Transport for the North

Research and Innovation in the North of England

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clarity from complexity

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Contact person: Dr Adam Brown, Cambridge Econometrics: alb@camecon.com

Authors: Dr Adam Brown, Cambridge Econometrics;
Dr Jen Nelles, University of Sheffield

Contributors: Prof Dieter Kogler, University of Dublin;
Kostas Gkrimmotsis, Alex Frost, Cambridge Econometrics;
Dr Paul Vallance, Dr Kevin Walsh, University of Sheffield
Prof Tim Vorley, Oxford Brookes University

Project director: Dr Ben Gardiner, Cambridge Econometrics

Steering Group: Emma Wood, Tim Foster, Transport for the North;
Dr Rick Holland, Innovate UK;
Richard Baker, North East LEP;
Dr Annette Bramley, N8 Research Partnership;
Sarah Bowes, WYCA

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Executive Summary

Introduction

The UK economy is characterised by pronounced, and increasingly widening, gaps in regional prosperity. While London and the Southeast surges ahead on an array of indicators, other regions, including the North, are redoubling efforts to strengthen their economies and are seeking evidence-based and contextually relevant advantages to anchor their strategies. These efforts are particularly salient to bolster post-Brexit regional resilience. It is in this context that TfN has commissioned a series of research projects to profile the economic strengths and opportunities in the region, inform the organization's transformational transport investment programme, and support business cases for infrastructure development.

This report builds on a considerable foundation of research already completed through this scheme to generate a more detailed understanding of what factors can meaningfully influence productivity growth in the North, specifically by exploring innovation performance and innovation diffusion. While many factors interact to drive productivity performance the focus on innovation emerged from local and national sources that identified research and innovation, including the factors driving these, as crucial for transforming the North's economy and providing societal benefits as set out in the NPIER.

Innovation is regarded as a strong driver of productivity in firms and across economies. In brief, adopting innovations in products, processes, and/or management practices is likely to increase firm efficiency and be reflected in productivity performance. Consequently, economic policy tends to put strong emphasis on developing innovation capacity – usually by stimulating knowledge generation – and innovation adoption – by encouraging increases in absorptive capacity and easing pathways for knowledge diffusion. Although a robust literature has emerged offering theoretical and empirical insights into the factors that drive innovation and productivity outcomes generally, these are most useful for formulating general policy directions.

Developing effective interventions requires that these insights be properly evaluated in the specific context of target economies. As such, there is considerable appetite for studies like this that specifically aim to understand how the drivers of innovation interact in the North of England to produce opportunities for policy to stimulate growth.

While the evolving evidence base contains important ingredients for answering these questions – including the Science and Innovation Assets; NP11 and Innovate UK efforts to list innovation assets and strengths; as well as work undertaken in support of the development of LISs and other regional development strategies – it is also important to understand how these factors are linked and how innovation networks operate in the unique context of the North's spatial and economic geography.

Summary of project objectives

The project addresses the wider question: what factors can meaningfully influence productivity growth in the North? Building on this we generated a series of sub-questions that shaped our approach to the issue, they were:

- How does innovation happen within a geography and how does that knowledge and technology diffuse throughout the economy?
- What are the drivers, enablers, and barriers to these processes?
- What do key indicators tell us about how Northern LEPs perform relative to each other and the rest of the UK?
- What questions do these results raise and how might they be tested to deepen our understanding of the North's innovation landscape?
- How do these results align with or diverge from those of previous studies in this area?

The four stages of our approach:

- A literature review and synopsis of the nature of the innovation process and the construction of a logic map of its main drivers, enablers and barriers. (see C2)
- The collection and analysis of a wide variety of indicators intended to capture these metrics, allowing comparisons of the North to other areas of Great Britain, while also investigating spatial patterns across the region itself. (see C3&4)
- A deep dive into patent and Innovate UK funding data focusing on the evolution of regional knowledge spaces and the role of innovation collaboration networks. (see C5&6)
- A series of three case studies of innovation clusters in the North, demonstrating the application of the logic map to real-world examples. (see C7)

We answer these questions by developing a detailed logic map of the factors that we think influence the innovation process and use this as a framework for a comparative analysis of innovation indicators across English LEPs. We then tested several hypotheses that emerged from those findings through a deep exploration of technology, sectors and networks using patent and research collaboration data. Finally, we demonstrate the applicability of the logic map in a series of cluster case studies. While this executive summary highlights some of our key findings our overall conclusion is as follows: Innovation is a multifaceted process influenced by an array of drivers and enablers that interact in complex ways. Using the framework that we provide here, policy makers can both seek to understand how those factors function within their specific geographies to diagnose weaknesses and identify critical paths for intervention. At the scale of the North, we argue that there are opportunities to use these insights to build on the specific assets, capabilities, industrial legacy, and economic geography of the North. Of the core drivers, we identify the potential to develop collaboration network density both within the North and across the UK as well as opportunities to identify and develop promising sectors and technologies in the region's knowledge space. The report and its appendices provide details about high potential technology classes for each of the LEPs.

Our key findings:

- Innovation is not a single event or outcome, but an interconnected process involving multiple interdependent stages, each with their own spatial and institutional context.
- Each stage of the innovation process is driven and enabled by a web of interconnected factors, and effective policy intervention depends on understanding strengths and weaknesses across the whole system.
- A comparison of LEPs on innovation drivers and enablers reveals that performance differences should not be reduced to a narrative about North vs. South. Rather, the contours of high-performing areas span regional boundaries prompting us to think more critically about spaces of innovation.
- An investigation into patterns of patent filings data from 1986 to 2015 confirmed that the North has been outperformed by the South of the country in terms of patent growth in almost every technology class.
- However, long-running Northern specialisations in chemistry, materials science, textiles and process engineering, have been augmented with a promising emerging specialisation in physics and electricity over the past decade.
- By measuring levels of technological diversity and relatedness, we were able to identify LEPs with the highest potential for future knowledge recombination. LEPs in the North on average performed at around the national average. However, the ability of an area to exceed its intrinsic potential on this measure is linked to its ability to collaborate effectively with across a wider network.
- An analysis of collaboration networks across Great Britain reveals dense collaboration networks spanning the area of Southern England previously identified in our earlier analysis, but sparser outside of this area. Whilst London is a key hub, other regional hubs exist in the South, the East, and the Midlands. There is no significant regional collaboration hub in the North.
- Key insights here were that innovation excellence is not limited to large urban agglomerations, however larger cities do have crucial roles to play as hubs of collaboration. The role of the public sector in “crowding in” private R&I over the long-run was also identified.
- Analysis of the digital health information systems (Leeds City Region), offshore wind energy (North East), and chemicals and process industry (North West) clusters showed that while they are anchored by strong public entities and/or large firms, have well-developed research infrastructure, and generally robust talent pools, firms have encountered difficulties in accessing and circulating locally produced knowledge and tapping into resources outside of the region.

These conclusions feed into specific actionable insights (see full recommendations, below) but also highlight some remaining questions that could help more effective targeting of policy interventions. Among these, we are interested in the degrees to which LEPs in the North share similarities with other areas across the country – and perhaps the degree to which these might be targets for further network development. Policy makers would also benefit from exploring in more detail historical and contemporary trajectories of technological development to help better understand how to build on existing and emerging specialisations in the North. More work on the nature of existing pan-Northern and national innovation networks would also be useful to hone policy objectives and design.

Details of findings

The innovation process and logic map

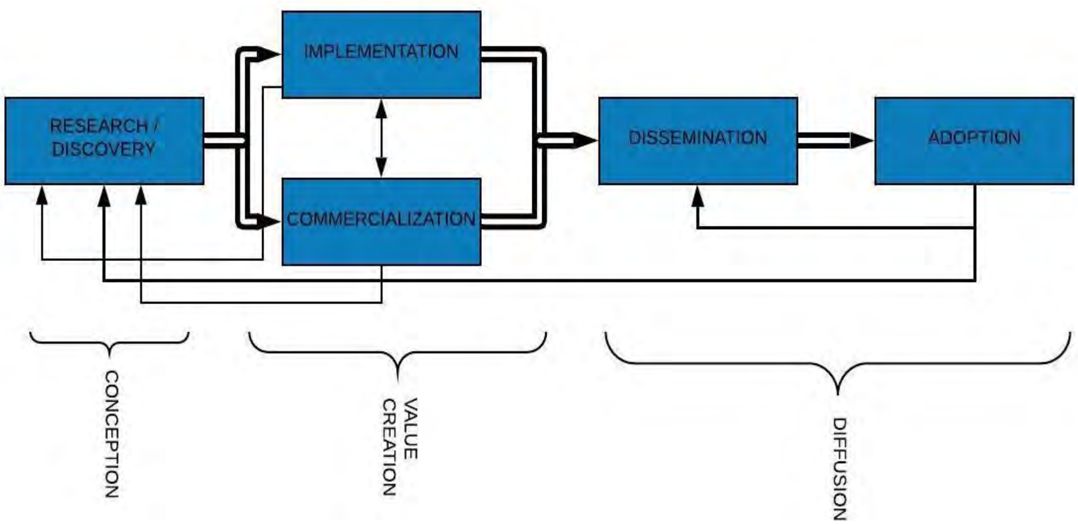
The logic map conceptualises innovation as a process and not just as an outcome. In our map, the innovation process comprises three phases through which multiple paths are possible:

1 **Knowledge creation:** where ideas are generated through research or processes of serendipitous discovery.

2 **Value creation:** where ideas are either implemented internally within firms (e.g. as part of their production processes), or commercialised through any number of channels.

3 **Diffusion:** involves the broader adoption of the innovation throughout the economy. This has two phases – one in which the innovation is disseminated (pushed) to markets and through networks and a second where that innovation is adopted (pulled) by entities for their own implementation or research/discovery purposes.

Figure 1: Stages in the Innovation Process



This is a dynamic and not necessarily linear process; each of the links in the innovation process has the potential to stimulate activity at other phases. Innovation policy should be careful of prioritising one phase over others. Furthermore, this conceptualisation helps to highlight that the links and pathways between phases are as important as measures of performance at each stage. In other words, we should think about the effectiveness of pathways and give some consideration to what kinds of attrition might be occurring along the way (and why).

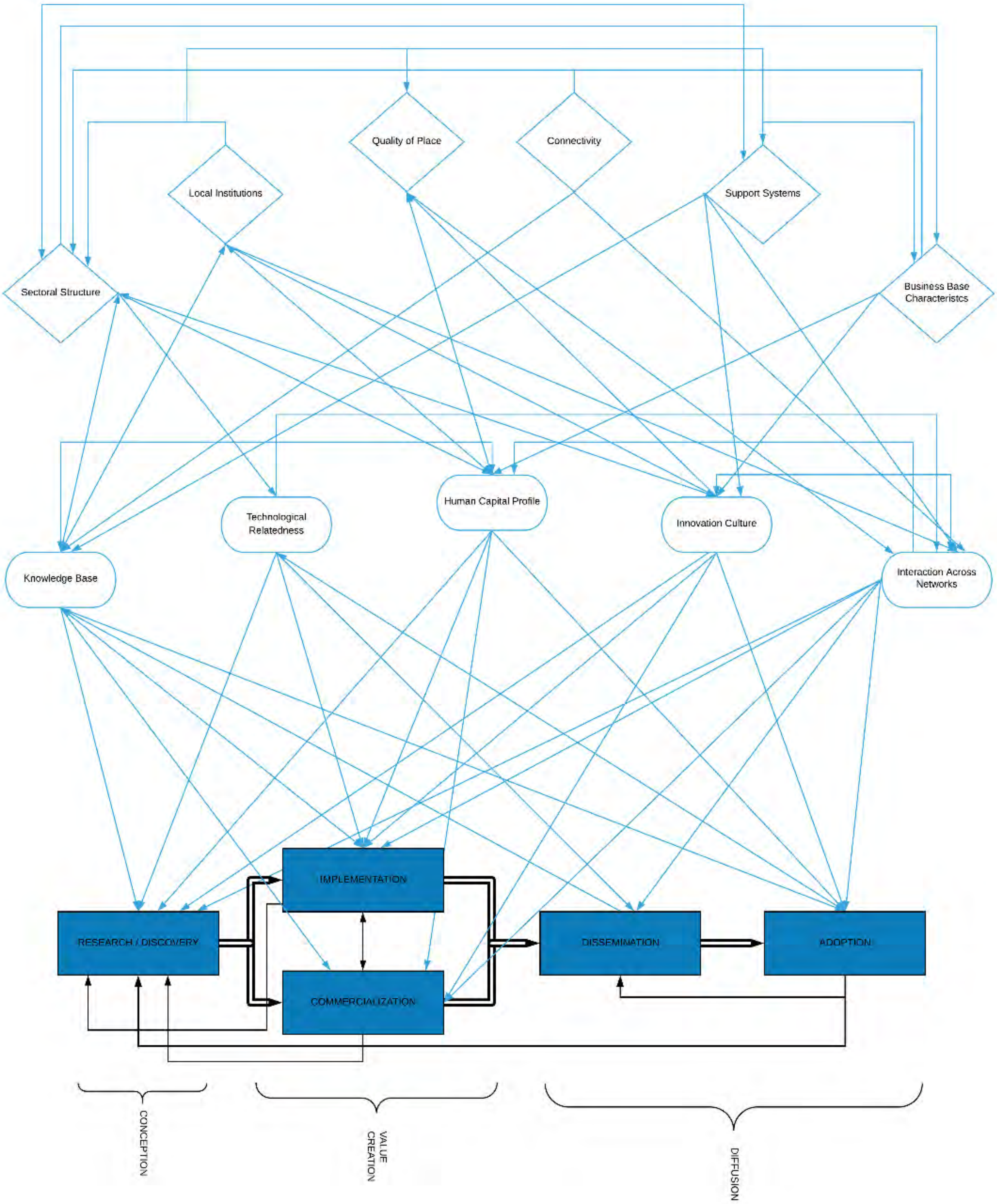
Dividing the innovation process up into three interlinked stages allows us to begin to identify relative strengths, weaknesses, and mismatches across the entire innovation chain, within different spatial areas. For example, whilst one geography may excel at creating new knowledge in a particular technology or domain, it may perform poorly at implementing or commercialising that knowledge. Understanding how the innovation chain of any given technology functions across space, and where the key linkages are, has the potential to provide clear insights into current weaknesses and opportunities for improvement.

Disaggregating the innovation process into these three stages also allows us to make an important point about the effect of drivers and enablers. Critically, we argue that the combination of drivers and enablers, the nature, and magnitude of their impacts will vary across stages of the innovation process. For example, knowledge bases play obvious and important roles in the knowledge creation process - it is the raw materials from which innovations are constructed. Yet in latter phases - value creation and diffusion - it may equally refer to the knowledge pool that managers will draw from (for instance) in order to prioritise resource allocation and investment decisions. Acknowledging this potential for variation in function and impact of drivers at different stages of the process adds important nuance to what might otherwise be conceptualised as a static relationship.

Our drivers and enablers are conceptualised as interdependent - part of a system in which the various elements have influences on one another - instead of as merely inputs that sum to observed outcomes. The connections that we highlight[1] between them may appear complex but that is the fundamental point. Making the intricacy of these interdependencies explicit can, perhaps counterintuitively, help clarify our understanding of the dynamics at play in a given context. As a conceptual model, this map has value in helping to highlight the importance of understanding these dynamics in any policy decision; for example, a policy to facilitate innovation by improving regional skill levels cannot be considered in isolation from important regional pull factors such as quality of place, connectivity and public research institutes. However, in Chapter 7, we demonstrate that it has even more power in context and can also be applied to map and understand pinch points and critical pathways for intervention in specific geographies (in that instance, clusters).

[1] It is perhaps appropriate to reiterate here that we do not claim that these connections are the only ones or that the understanding depicted in our logic map is comprehensive. While our work was based on a careful review of the literature systems dynamics approaches demand that we acknowledge that these can function in very different ways in different cases and that, in policy, there are no universal laws. That said, we believe that this map is an effective depiction of relationships at this level of conceptual granularity.

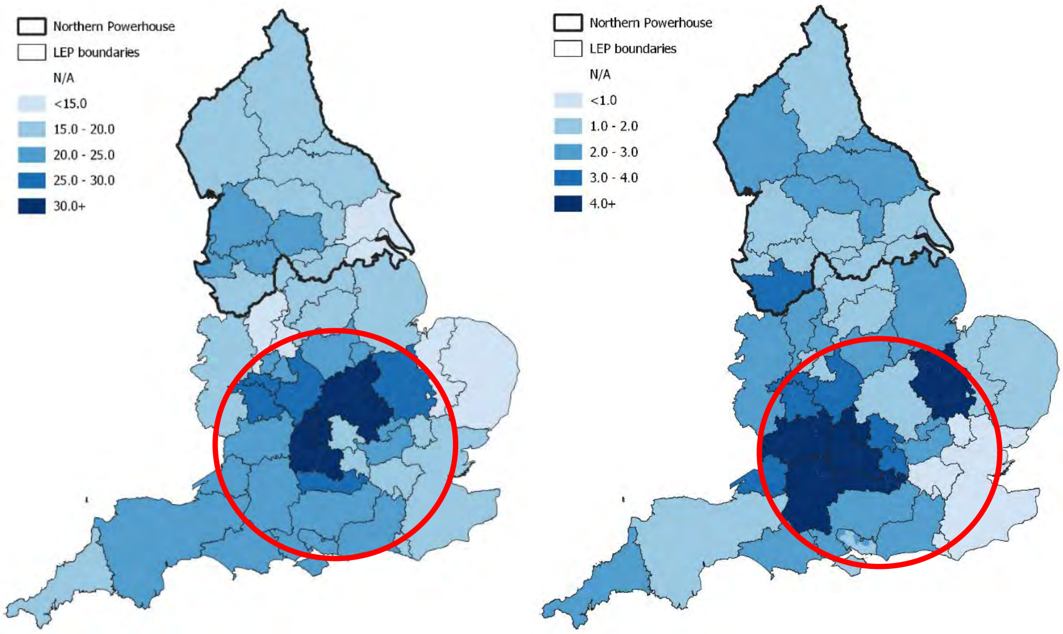
Figure 2: Logic Map showing primary connections between enablers, drivers, and innovation metrics



Evaluating the innovation process in the UK

We used the logic map in Chapter 3 to frame our evaluation of innovation performance and the potential of the economy in terms of both drivers and enablers. At this level of analysis, we focused primarily on operationalising and measuring indicators to explore patterns of strengths and opportunities for improvement and did not attempt to fully elaborate the quantitative relationships between logic map elements. Our analysis revealed a number of interesting patterns, summarised in more detail in Chapter 4. We looked at patterns of performance both across the UK, and within the North more closely. The data suggested that an area of central, southern England performs particularly well across a wide range of innovation metrics. This high-performance area does not conform to a specific NUTS1 region but includes all of London and part but not all of four different regions: South East, South West, West Midlands, East of England. This encouraged us to seek lessons that can be learned from both this area and inspires us to think about innovation ecosystems, and high-performance areas, in ways that are not necessarily bound by existing regional geographies.

Figure 3: Proportion of firms undertaking R&D (%), left, unique CPC patents per 10,000 adults, right



Some observations about the characteristics of this high-performance area hold potential insights for the North:

- Firstly, proximity to a major world city, and to a secondary degree its surrounding international airports, are of clear benefit. The area benefits from strong involvement with multinational corporations and venture capital. Although much of the innovation activity occurs outside of London, the role of London as a convening and networking hub is clearly crucial. A question that might arise is the extent to which larger cities in the North are able to facilitate innovation in their surrounding areas in the same way.
- Although there are a number of cities spread around this high-performance area within the South of England, as a whole the area is largely rural or suburban in nature, with a range of smaller, historic cities, and market towns. It could be speculated that the advantage this brings is in the

variety of lifestyle offers available to mobile knowledge workers both from the UK and from further afield. Indeed, the data shows that this area is particularly adept at attracting and retaining knowledge workers. There are two implications here for the North; firstly, the importance of generating a high quality of life offer, and secondly, the role that rural areas and smaller historic cities can play in the wider innovation system.

- The key to the success of the wider ecosystem is the extent to which different geographic areas are able to both develop their own specialised niche within the whole, and then collaborate and share knowledge (during all stages of the innovation cycle) with neighbouring areas who have complementary specialisations. A network of knowledge generators, implementors, disseminators and adopters is thus created across a wide variety of knowledge domains, and through this process a system-wide related variety is ensured.
- Although the southern innovation ecosystem is evidently private sector led, the presence of long-established public institutions is also clearly a factor, not just in the generation of knowledge, but in the attraction and generation of knowledge workers, be these world-leading Universities at Oxford or Cambridge, or other public institutions such as DSTL and GCHQ, evidence of the ability of publicly-funded research to “crowd in” private sector R&I activity over the long-term.

Regional knowledge spaces, technologies, and sectors

In the first of the empirical chapters (Chapter 3) we focused on understanding the current state of knowledge spaces, across the region and for each of the LEPs. This research was centred on the question of what areas does the North specialise in, how are those specialties distributed (and how are they different) across the region, and how are they evolving over time? While previous research has tackled this question, it has typically focused on answering it using employment data. Our approach is novel to the extent that it explores this question through the lens of patent data, which because patents are one manifestation of innovation, we argue gives a more granular understanding of knowledge and value creation in the region. In particular, because this approach highlights innovation output rather than other measures of economic impact (e.g. jobs), it can provide insights into the economically smaller but highly innovative sectors contributing to regional productivity and identify areas where public support may enable firms to scale or increase investment to optimise impact.

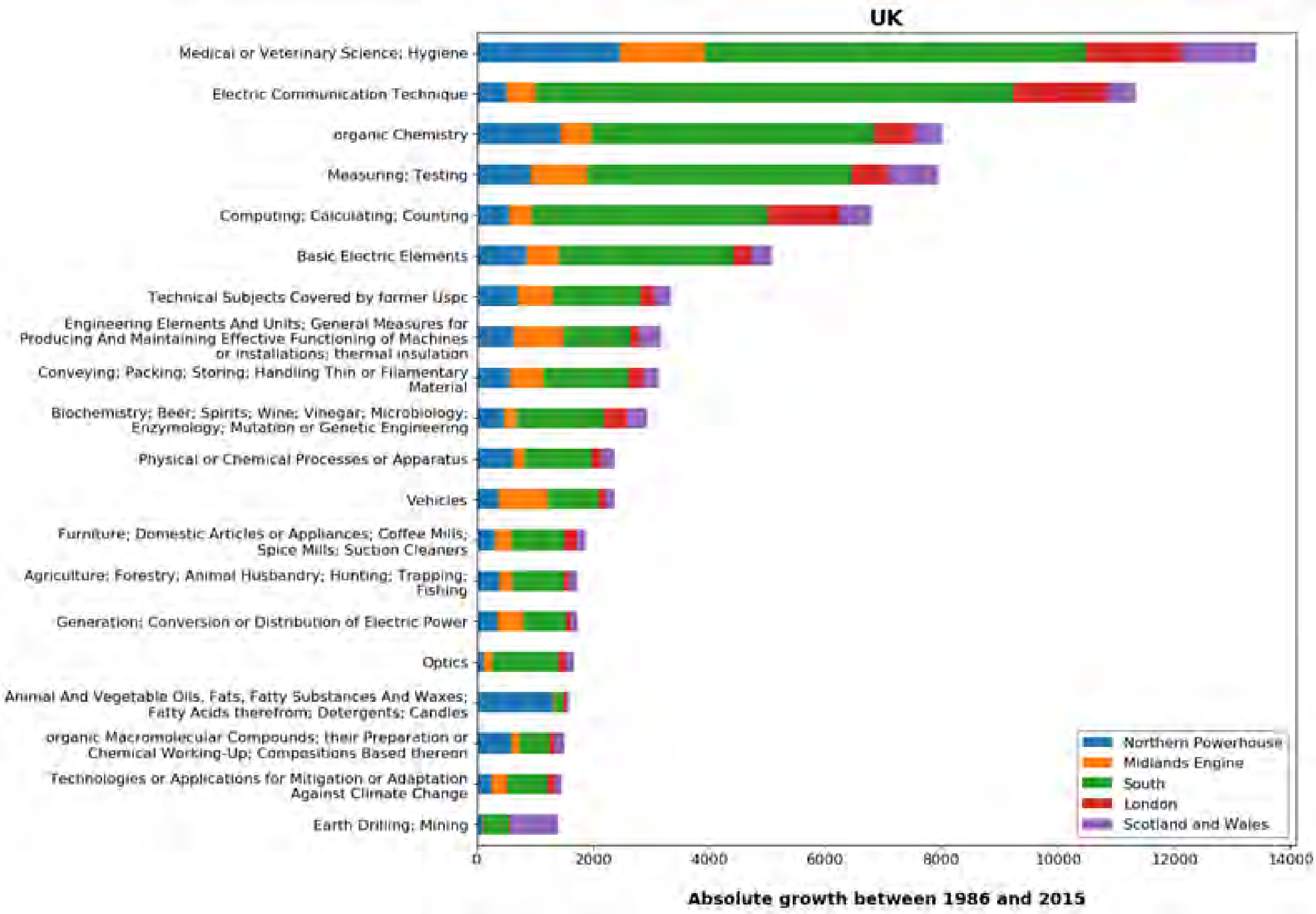
Through our analytical process, we were able to produce technological profiles of the knowledge space of Great Britain, its main sub-national geographies, and within England, individual LEPs.

This data revealed some interesting patterns of sub-national specialisation in comparison with other regions. By evaluating the frequency of patents from different classes we observed a typology of both geographical strengths and emerging trends.

- Within the overall Great Britain knowledge space, the North specialises in patents in the fields of chemistry, materials, textiles and process engineering.
- The LEPs of the Midlands Engine have relative expertise in heavy industry and engineering; vehicles, metals, pumps and engines.

- Finally, the southern part of the country is more dominant in physics, electronics and computing.

Figure 4: Contribution of different subnational areas to UK patent growth between 1986-90 and 2011-15 for the 20 fastest growing technologies



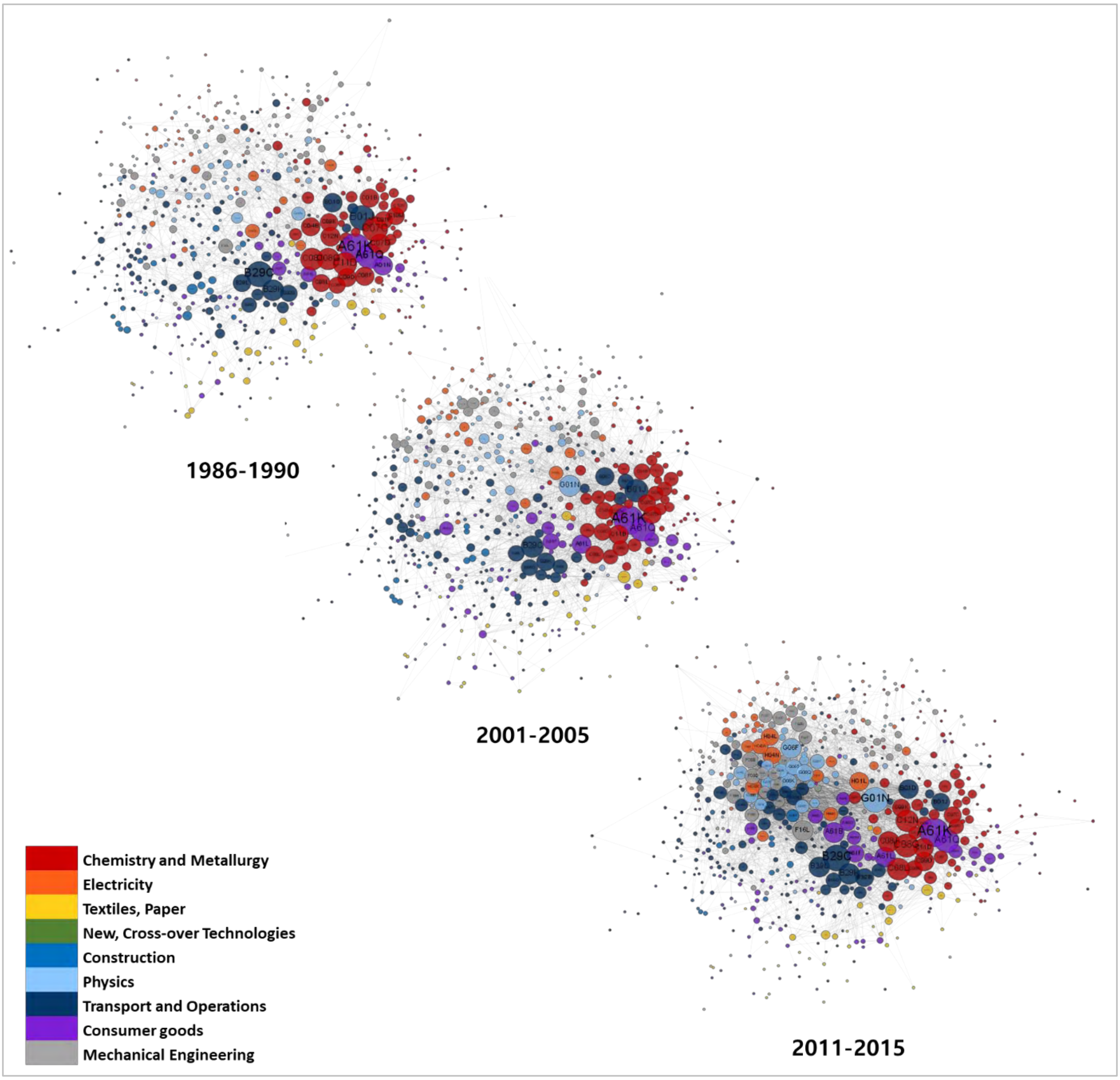
Source: PATSTAT, EPO; author's calculation

This is reflected in Figure 4, which shows growth in patenting classes between the periods 1986-1990 and 2011-2015 for Great Britain, and the contribution of selected sub-areas towards this. The South of England (South East, South, West, East of England) has provided the lion's share of this growth for the majority of classes. The North contributes to most areas; however it makes the most significant contributions to Medical or Veterinary Science & Hygiene, Organic Chemistry, Animal and Vegetable Oils & Fats, Physical or Chemical Processes, and Organic Macromolecular Compounds.

The analysis of the evolution of the regional knowledge space provides insight into the North's industrial history and reveals some clues about its future. As shown in Figure 5 below, a focus in the 1980s and 90s on technologies related to chemicals and metallurgy, consumer goods, transportation and operations, with some peripheral textiles and paper saw both convergence and deepening by 2015. More recently those central technologies have been joined by increased patenting output in technologies related to physics, electricity, and mechanical engineering, while some of the more traditional technologies (such as textiles and paper) remained relatively peripheral within the overall knowledge space, with limited connections to other domains.

Overall, the Northern knowledge space has seen an increase in density of interactions and clustering, indicating co-occurrence of technologies on patents and demonstrating that there has been significant cross-fertilisation between technologies. The cognitive proximity of some of the technologies in which the North exhibits strength suggests that this type of convergence will likely continue, and should be supported in doing so. A key question that emerges from this research centres on how this knowledge space is likely to evolve and what policy can contribute to directing, accelerating, deepening, and capturing the benefits of recombinant trends, including both the strengthening of existing trends, for example in the emerging physics and electricity cluster, and the addressing of noticeable weaknesses, for example better linking innovation in textiles to other knowledge domains.

Figure 5: The Evolution of the Knowledge Space in the North (1986-1990; 2001-2005; 2011-2015)



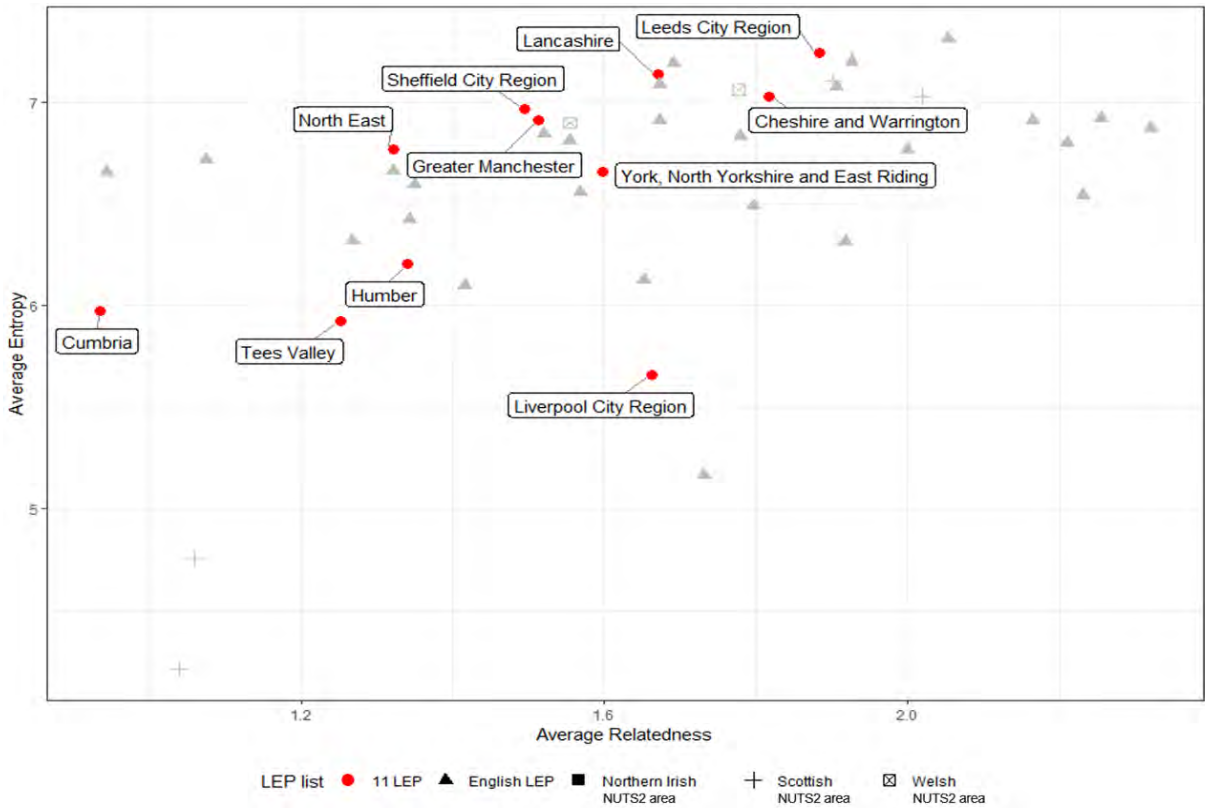
Source: PATSTAT, EPO; author’s calculation

Potential for recombinant knowledge production in the knowledge space

While understanding the evolution of existing specialisations can help guide development policy, this patent data analysis is most accurately a description of the past. While this can help shape expectations about the future, using this data and some novel methodologies, we can also develop models to help identify previously unknown technological areas with the greatest growth potential. One approach is based on the concept of recombinant knowledge, which posits that some groups of knowledge and artefacts are easier, and more likely, to combine than others. Understanding which types of knowledge, and technologies, are likely to come together in new ways can be a powerful tool to predict sources of innovation. This understanding can, in turn, help target policy efforts to seed and catalyse industrial development.

Our analysis of relatedness in patent data yielded insights along several vectors - namely, place and technology. The potential for innovation of a place can be determined by measuring its levels of technological diversity (entropy) and the similarity between knowledge classes in the pool (relatedness). The logic is that the places that score highly on both measures are likely to have the greatest potential for recombinant knowledge production. That is, they are places characterised by lots of raw material or building blocks for innovation and those blocks are sufficiently similar to one another that they can be effectively combined. In the North, places like Lancashire, Cheshire and Warrington, and Leeds City Region rate highly on recombinant potential. However, innovation networks inevitably cross LEP boundaries, and the ability of LEPs to exceed their potential according to this measure is likely related to their ability to collaborate effectively with the wider regional ecosystem.

Figure 5: New recombinant knowledge production at regional scale (2011-2015). The 11 Northern LEP areas are shown in red



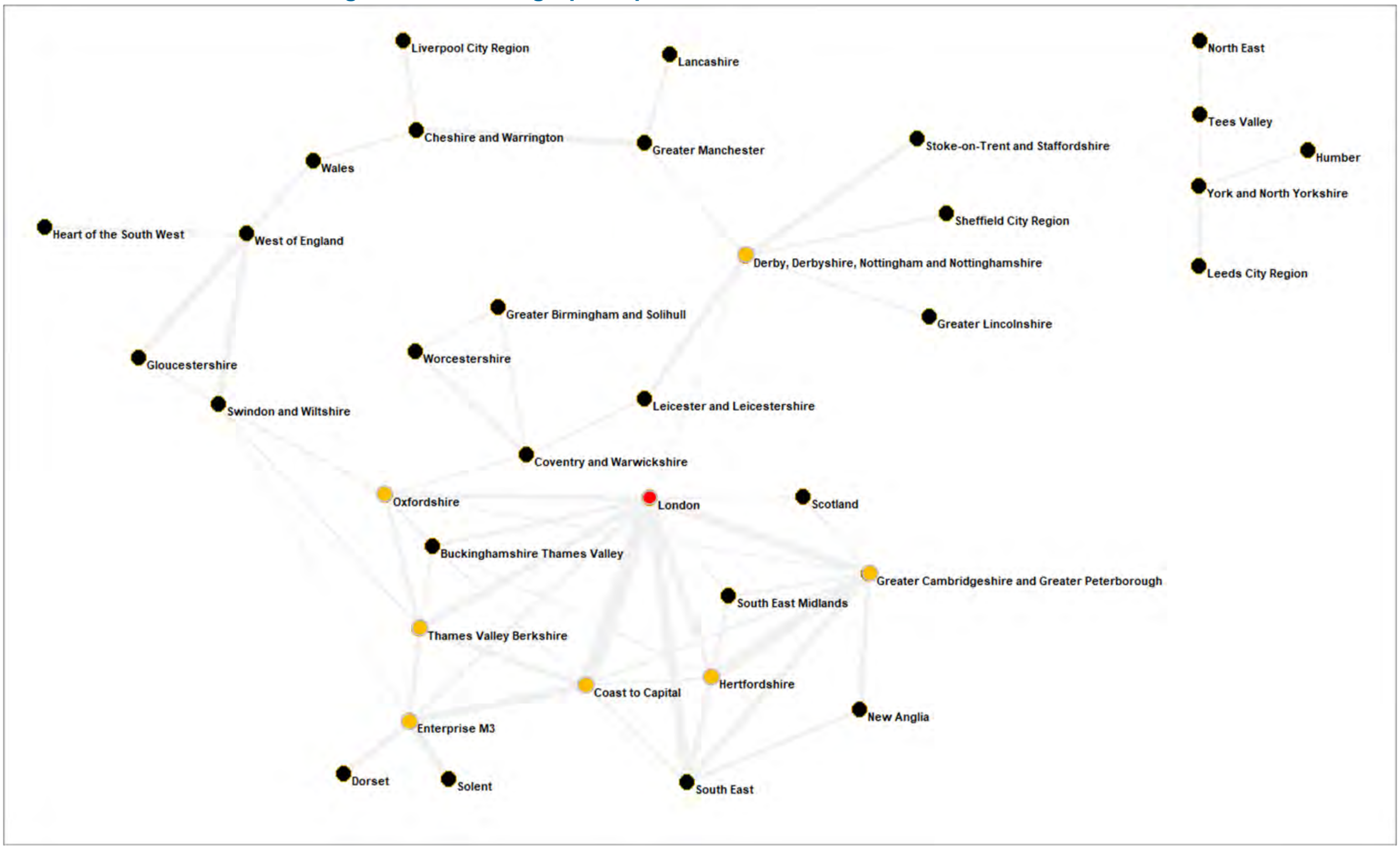
Source: PATSTAT, EPO; author's calculation

Innovation collaboration

Another question that interested us related to how knowledge was shared, or flows, across the North and to other parts of the country. To better understand who is involved, and in which sectors, in innovation collaborations we could get a better grasp on the extent to which Northern innovators are connected to each other and broader networks. Here we relied on data from Innovate UK funding applications on research collaborations and compared it to our data on patent co-inventors.

This analysis proved interesting and, we think, tells an important story about how knowledge is flowing and being leveraged across the UK. Exploring the inter-LEP patent collaboration showed that co-invention tended to follow regional trends, with the majority of collaborations taking place within a single LEP or between organisations in nearby or neighbouring LEP areas. A distinct difference between the Greater South East and the rest of the UK immediately apparent, with a single dense collaboration network covering an area roughly coincident with our "high-performing region" identified above. Organisations in Southern LEP areas collaborate frequently with the majority of their neighbouring LEP areas; seven Southern LEPs had a degree centrality of 6 or above, whereas only one Midlands LEP, D2N2, did; and no Northern LEP area. The North and Midlands innovation ecosystems, on this measure, are less dense than that of the wider South East, with most LEP areas only having strong collaboration links to one or two of their closest neighbours. Formal collaboration doesn't happen to the same extent and we can infer that knowledge is also not being shared as efficiently.

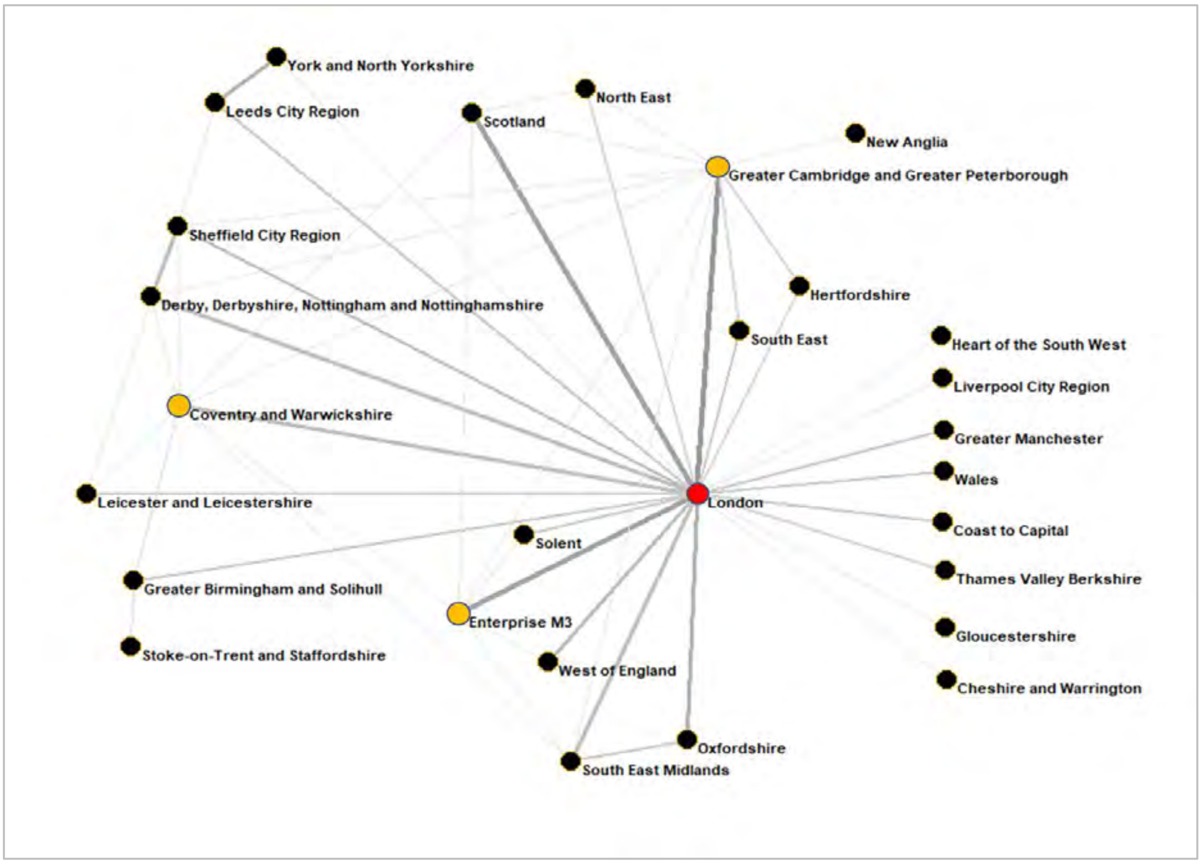
Figure 6: Network graph of patent co-inventions



Source: EPO, PATSTAT; author's calculations

Patent data is a useful lens through which to examine innovation performance and potential, but it is important to recognise that this form of commercialisation represents only a fraction of the innovation in an economy. The Innovate UK research collaboration data shows a similar picture but with important differences. Using this dataset, the UK research collaboration network appears more centralised around London, with the majority of LEP areas having London as their main collaboration partner. Other nodes with 6+ connections appear to act as secondary regional hubs: Enterprise M3 in the south, GCGP in the east, and Coventry and Warwickshire in the Midlands. Sheffield City region is the closest to a northern hub, with 5 connections, albeit only one of these is to another northern LEP area (Leeds). The lack of a significant sub-regional network focused around the North is indicative.

Figure 7: Network graph of collaborative research projects



Source: Innovate UK; author's calculations.

The other useful insight to come out of this analysis of Innovate UK data was the role of public sector institutions within collaboration networks. Here we found that London and Scotland have disproportionately high levels of public sector and university involvement, whereas other strong Southern LEP areas, such as GCGP, Oxfordshire and Enterprise M3 participation is dominated by private firms, with far less reliance on public sector institutions.

Stronger performing Northern (and Midland) LEPs have higher levels of university involvement than Southern LEPs, however this is not true of all Northern LEPs, with those with lower levels of overall participation also having lower relative levels of university sector participation. Cheshire & Warrington is something on an exception here. This may indicate the role of the university sector as an important leveraging factor for increasing the involvement of local firms. However, *in general*, Northern and Midland LEPs appear to be more reliant on university and public sector involvement than Southern LEPs – with the notable exception of London.

Clusters

Our rationale for doing a case study of clusters in the North (see Chapter 7) was driven primarily by an interest in exploring how the elements of the logic map played out at smaller geographies and to test the value of the map as a tool for evaluating cluster development strengths and opportunities. In this latter objective, we aimed to highlight and explore critical pathways - chains of drivers and enablers that functioned as bottlenecks or barriers in the innovation process - identified by local stakeholders. Our research focused on the digital health information systems (Leeds City Region), offshore wind energy (North East), and chemicals and process industry (North West) clusters. While these clusters were very different - in geographies, markets, stages of development, industrial structures, and strengths in the innovation process, among others - we found some interesting parallels between them.

The three clusters shared several commonalities:

- anchored by strong public entities and/or large and internationally significant firms.
- well-developed research infrastructure with universities with specialised programmes and centres, technology transfer services, and/or national labs nearby.
- robust talent pools and two of three were anchored by industry/cluster organisations.

In sum, these clusters have a lot of the necessary raw material to drive innovation. We argue that the greatest opportunities to improve performance across the innovation process centre on how to more effectively leverage local capacity and access external assets.

Arguably, all three clusters suffer from the same issues. Viewed from the outside, they appear to perform well on (aspects of) all three stages of the innovation process. However, the links between those could be more effective. For instance, all have impressive knowledge creation capacity, but they struggle to capture as much value as exists from that knowledge base. The value creation to diffusion links also appears to be weak across all three clusters. While evidence is less robust on this metric, weak knowledge circulation may be having the effect of reducing the adoption of locally generated innovations. Critically, while these clusters may perform well on the individual metrics these are the product of the activities of firms that *were able to* reach markets and *were able to* access and adopt often externally generated innovations. Capturing unrealised potential represents a significant opportunity for future cluster development.

In each case, the causes of these weak links are slightly different - the drivers and enablers involved in creating these conditions vary. However, we identified some commonalities in the critical paths particularly engaging culture and network drivers and the business base characteristics enabler.

- Weakness in cluster innovation cultures, particularly on the themes of risk tolerance and willingness to participate in knowledge sharing and open innovation processes.
- Difficulty accessing networks. Stakeholders noted that while connections existed within the cluster and sector that they were sometimes limited, or difficult for certain firms to access. This was particularly the case with respect to links with higher education and public research, strategic partnerships, and accessing potential clients and markets.
- External networks were largely ad hoc and underdeveloped. While some firms and research organisations have well-developed links, connections between entities in different clusters, even those that were relatively close proximity in the North, appear to be less developed. While we acknowledge that without more empirical research this finding is difficult to substantiate the consistency of our findings across clusters suggests that fostering cross-jurisdictional partnerships might be a significant opportunity to increase knowledge circulation and, relatedly, value creation, diffusion, and growth.
- These patterns appear to be being influenced by business base characteristics, which are similarly dominated by SMEs across clusters.

These observations were very influential in developing the recommendations addressed below but also reinforce many of the findings of the previous chapters.

Recommendations

We build on the findings described in the summary above to develop actionable recommendations for research and innovation development in the North. While the work that we've done here covers a great deal of territory, and effectively answers the questions set out at the beginning of the project, it has also raised lots of questions and suggested areas of future research. Here we draw out the common themes across chapters to offer some insight into the issues that are relevant across the broader Northern economy.

Our key recommendations for Northern policy makers:

- Avoid appealing but linear arguments; instead conceptualise innovation as a series of interlinked but separate stages, driven by a series of mutually interdependent drivers. Innovation interventions must be designed to mesh with wider policy, from business support and infrastructure provision, to spatial planning and skills and education.
- Learn the right lessons from the South; identify a complementary vision for the North by understanding how and why high-performing innovation ecosystems are able to leverage their assets and capabilities through collaboration and related variety, rather than attempting to replicate exact environmental conditions.
- In post-COVID Britain, there is both a necessity and an opportunity to improve the generation, attraction and retention of knowledge workers through a combination of lifestyle offer and employment opportunity, and the public sector has an important role to play in both of these.
- Identify specific opportunities for knowledge recombination and increased effectiveness through all stages of the innovation process, and use network strategies to connect sectors with high potential for recombinant knowledge production.
- Encourage and facilitate LEPs and other sub-geographies to identify and pursue their own role within the national and sub-national innovation ecosystem, in particular looking at the areas for future research identified below.

Reconceptualise the innovation process and its drivers

In this report, we've conceptualised innovation not as a single event, but as an interconnected process involving multiple stages. This is a dynamic and not necessarily linear process; with the right conditions, each of the links in the innovation process has the potential to stimulate activity in other phases. Recognising that knowledge creation, value creation, and diffusion (and their internal variants) function as linked elements that produce and sustain innovative outcomes enables more intelligent and effective policy design. Identifying not just which technologies a geography specialises in, but also the extent to which it is active in different stages of the innovation process, is crucial to identifying weak links and critical pathways through the innovation system. Strengthening and deepening networks both within and between LEPs is likely to be a crucial part of any policy designed to help join up the stages of the innovation process.

Similarly, our approach also views drivers and enablers as interconnected and interdependent. We see these as part of a system in which the elements influence one another, and have different impacts on different stages of the process, rather than as one-dimensional inputs. For any policy aim, we recommend thinking through not only which drivers and enablers influence outcomes, but how they combine and interact with each other to impact innovation. Our method of identifying critical pathways is one such approach. Any policy design that seeks to study and address a single driving factor in isolation is likely to misdiagnose both the problem and the solution.

We also want to reiterate that innovation itself doesn't exist in a vacuum. This suggests that policies that seek to improve innovation outcomes will be more effective if they are designed in conjunction with wider policy objectives that don't necessarily have innovation as their primary aim. These include, for example, policies to improve skills, education provision and social inclusivity; to improve profitability, productivity, and resilience in the SME base; to improve quality of life, of place and of underlying infrastructure; and to tackle specific challenges, from climate change to global pandemics. These initiatives should be designed to work together to more effectively underpin innovation outcomes.

Craft a unique vision for the North

It is difficult to engage in innovation policy in the UK without looking for inspiration to the South of England, as on most metrics the Southern part of the country performs better and more consistently. Indeed, our metrics identified a high-performing area incorporating London and parts of four surrounding regions, that excelled both in terms of indicators of all stages of the innovation process, but also across a wide range of drivers and enabling factors. There are specific lessons that can be learnt from the success of this region in developing an effective innovation ecosystem, particularly in the combination of factors that enable it to attract and retain both a high-skilled workforce and an entrepreneurial knowledge-focused business base.

However, the success of the South relies on a unique combination of industrial specialisations and economic geography not in evidence in the North, not least the presence of a major global city. We recommend that stakeholders within the North work to develop a vision that learns lessons from the basis of success in the South but also takes into account the specific assets, capabilities, industrial legacy, and economic geography of the North. This will involve a dual process of developing a deeper understanding of why this high-performing region in the South of England is successful (not just how), and of how this insight can be applied to the specific context of the North, with its own unique strengths and capabilities, not least its more poly-centric urban nature, its coastal assets, its enviable collection of research universities and Research Technology Organisations (RTOs), and its invaluable industrial heritage. Needless to say, the role of the North has to be developed in concert with the rest of the country, implying the necessity of either cross-regional co-design and/or a role for central government, with funds being made available in sufficient quantity to execute this vision, once identified.

Build collaboration network density across the North

While strong localised cluster networks are clearly important for the innovation process, longer range networks are also critical. These provide important infusions of knowledge as firms and knowledge producers connect with other concentrations of expertise. These are also important vectors for innovation and technology diffusion that can provide new tools and inspiration to strengthen local innovation efforts. Knowledge that enters a LEP area through an external network contact can then diffuse through local networks. Organisations and individuals that interact both locally and externally have an important role.

One specific strength seen in the south of the country is the deep and dense network of collaboration between LEP areas. This shows up in both patent co-invention statistics and Innovate UK funding data. There is clearly an element of bi-causality with the overall level of innovation activity in the south, and the density of the collaboration network. However, we specifically recommend that if the North is to emulate the success of this area, it must find a way to increase the range and depth of collaboration at a pan-Northern level. We recommend that stakeholders in the North connect with other nodes in the regional and national innovation ecosystem to build and strengthen connections between firms and organisations across jurisdictional boundaries and to build a denser collaboration network both across the North and with neighbouring areas. An existing level of collaboration between organisations in the North and those in the Midlands should not be side-lined here; opportunities for complementarities, synergies and useful knowledge exchange do not only follow regional boundaries.

Identify specific opportunities in knowledge space

In chapter 4, we identified the necessity for the North as a whole to identify its role within the UK knowledge space, and for each LEP area to identify its own relatively more specialised role within this vision. The data presented in Chapter 5 provides compelling evidence of the evolving technological specialisms in the North and the detailed analysis of core technologies is a rich resource to help focus policy attention. Translating technology classes into opportunities involves a) taking stock of what industry sectors produce and exploit technological knowledge, and b) identifying where to support the development and establishment of industry sectors that are currently underrepresented based on the technological profile of a region or nation.

At the scale of the North, our data indicates a number of technologies and sectors that present the opportunity for further growth in innovative output. We suggest that it is in these areas where policy intervention could be geared towards sectoral support. Developing strategies to increase the share of such sectors in the regional economy would be beneficial for local business creation and growth, as they would find an innovative environment that would allow them to gain a competitive advantage over firms that are based in localities where the specialised knowledge that is essential for these particular sectors is not available. Furthermore, policymakers should explore opportunities to deepen networks in order to more effectively embed them in localised, regional, and national innovation ecosystems.

Theory suggests that the critical role of geographical sub-areas (such as LEPs) within wider regional innovation ecosystems is to identify and build their specialised role within the wider, more knowledge-diversified regional system, which may or may not strictly conform to the pan-Northern geography. The data presented in the main report and appendix provide numerous opportunities for LEPs to (re)consider areas of industrial specialisation and local sectors with the greatest innovation potential. By tracking and exploring the evolution of their knowledge spaces presented in this way, LEPs would be able to identify local specialisations and technological trajectories and pinpoint technologies and industries with the potential to emerge more significantly as innovation drivers. There is significant scope for more research on how knowledge spaces evolve and why they change as well as to develop analytical tools to more accurately predict areas of potential growth.

Areas for Further Research

This project produced some useful insights but also suggests several more strands of research that would expand on our initial findings. While we recognise that stakeholders at various scales have roles to play in shaping the Northern innovation ecosystem, here we focus specifically on the steps that LEPs can take to better understand their role and areas of potential intervention. These have been conceptualised as broad questions to structure what we hope will be a next phase in the process of innovation ecosystem development.

- Are there commonalities in the technological specialisms and development trajectories of the LEPs that suggest potential for collaboration, cross-fertilisation, and policy co-development? Note that our research indicates that Northern LEPs might share similarities with LEPs outside of the North, which might indicate a broader potential for network development outside of the traditional geographies of the region.
- The knowledge space and recombinant knowledge potential analysis produced a wealth of data on specialisation and innovative potential for each LEP. What pathways do these particular specialisms, technological trajectories, and patterns of collaboration suggest for ecosystem development? The answers will differ for each LEP and will likely require deeper analysis of the rich results to enable each region to understand its functional strengths and its role in contributing to related variety in the North.
- Building on the previous questions and our conclusions about hierarchies of specialisation (Chapter 4) and technological relatedness (Chapter 5): What can be done to help areas within the North continue to develop and build on their own specialisations, and then develop the right connections and networks to ensure that the right knowledge is disseminated between the organisations who can make best use of it?
- Are intra-regional networks between places in the North actually as weak as they appear in this study? If so, why, and are there opportunities to develop them? If not, how are they functioning to support the growth of localised economic activities?
- We can ask similar questions about the status of networks between Northern LEPs and other places. Which connections are most developed and why? Are there any gaps? Are there opportunities to rethink the geographies of these connections and position Northern actors more effectively within national ecosystems?
- How can we more effectively capture innovation? Patent data and collaborative research partnerships offer a window into specific types of innovation, but process innovation and other intangible outputs are difficult to systematically measure. Does innovation performance across the region differ in process versus other types of innovation? What implications does that have for productivity policy?
- Our recommendations focus on developing networks, both internally to LEPs and externally – towards national innovation ecosystems and engaging in policy co-design with partners at different scales as appropriate. However, these are not costless or simple to achieve. As partners come together to consider collaborative strategies it might be useful to explore areas in which the capacity to partner effectively, and

execute expected roles, may itself benefit from intervention and support.

- The logic model proved to be a useful tool for understanding both local and more regional drivers and enablers of the innovation process and for evaluating performance. This tool can be deployed at the LEP scale to explore the entire ecosystem or can be focused, as we have done here, on understanding particular geographically-concentrated industries and the factors that drive and enable their innovation processes.

In this report, we've been able to draw on a relatively rich array of data to explore the research and innovation landscape in the North of England. However, we encountered numerous limitations based on lack of data availability in key areas (the indicators don't exist), lack of data at appropriate scales (the indicators exist but not at the level of granularity that we needed to make comparisons at the sub-regional scale), and lack of timely access to necessary data (the data exists at the right scale of analysis but could not be accessed within the timeframe of the project). We are certainly not the first to comment on the lack of appropriate data to measure innovation and indicators of productivity. The Industrial Strategy Council recently published a list of key data gaps in their evaluations of the Industrial Strategy[2] To these, we would add that there is a broader need for indicators, collected more frequently, that capture innovation activities beyond the data on patents, funding awards, and R&D tax credits. We also recommend that data be released at more spatially disaggregated scales and that these be available in sectoral classifications more befitting the contemporary economy. As the COVID-19 pandemic plays out, there will also be a high demand for all of this data to be released with more frequency so that changes can be assessed in as near to real time as possible. Finally, we also recommend that as much data as possible be declassified or that processes for secure access be streamlined to permit projects like this to make use of existing but currently excessively protected data.

[2] see https://industrialstrategycouncil.org/sites/default/files/attachments/success-metrics/Measuring%20the%20Success%20of%20the%20Industrial%20Strategy%20-%20Reasearch%20Paper.pdf page 16

1 Introduction and Context

1.1 The purpose of this report

The UK economy is characterised by pronounced, and increasingly widening, gaps in regional prosperity. While London and the Southeast surges ahead on an array of indicators[3] other regions, including the North, are redoubling efforts to strengthen their economies and are seeking evidence-based and contextually relevant advantages to anchor their strategies. These efforts are particularly salient to bolster post-Brexit regional resilience. It is in this context that TfN has commissioned a series of research projects to profile the economic strengths and opportunities in the region, inform the organization's transformational transport investment programme, and support business cases for infrastructure development.

This report builds on a considerable foundation of research already completed through this scheme to generate a more detailed understanding of what factors can meaningfully influence productivity growth in the North, specifically by exploring innovation performance and innovation adoption. While many factors interact to drive productivity performance the focus on innovation emerged from local and national sources that identified research and innovation, including the factors driving these, as crucial for transforming the North's economy and providing societal benefits as set out in the NPIER.

Innovation is regarded as a strong driver of productivity in firms and across economies. In brief, adopting innovations in products, processes, and/or management practices is likely to increase firm efficiency and be reflected in productivity performance. Consequently, economic policy tends to put strong emphasis on developing innovation capacity – usually by stimulating knowledge generation – and innovation adoption – by encouraging increases in absorptive capacity and easing pathways for knowledge diffusion. Although a robust literature has emerged offering theoretical and empirical insights into the factors that drive innovation and productivity outcomes generally, these are most useful for formulating general policy directions.

Developing effective interventions requires that these insights be properly evaluated in the specific context of target economies. As such, there is considerable appetite for studies like this that specifically aim to understand how the drivers of innovation interact in the North to produce opportunities for policy to stimulate growth.

While the evolving evidence base contains important ingredients for answering these questions – including the Science and Innovation Assets; NP11 and Innovate UK efforts to list innovation assets and strengths; as well as work undertaken in support of the development of LISs and other regional development strategies – it is also important to understand how these factors are linked and how innovation networks operate in the unique context of the North's spatial and economic geography.

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[3] See ONS (2020) Regional labour productivity, including industry by region, UK: 2018; OECD (2018), "OECD Regions and Cities at a Glance 2018", OECD Publishing, Paris; McCann, P. (2019) "Perceptions of regional inequality and the geography of discontent: insights from the UK", Regional Studies; NPIER

1.2 Review of Previous Studies

A short review of the findings of recent previous studies into the nature of the Northern innovation ecosystem is covered below: This is not intended to represent a comprehensive literature review, but rather a snapshot of recent analyses that have been carried out at either pan-Northern or NP11 LEP level.

Research Paper/Report	Key Findings
Innovation North – Progressing Innovation in the Northern Powerhouse by Steer Economic Development, 2018	• The North has a significant array of science and innovation assets, however on a range of measures it is currently punching below its weight in terms of innovation and the economic contribution it makes; • Sectoral strengths identified were categorised as low carbon & energy, advanced manufacturing & engineering, health & life sciences, digital, bioeconomy, and agri-food; • However there is a degree of fragmentation in relation to the coordination of assets and strengths, as illustrated by the varying approaches to innovation taken by different LEPs; • Geographically-based rivalries have hindered collaboration between LEPs and between organisations operating in different LEP areas; • Geographically-focused funding streams have hindered efforts to collaborate across LEP boundaries and/or on a pan-Northern basis, e.g. LEP funding is tied to a specific geography; • 'Vertical thinking' in institutions and by their funders has hindered collaboration between sectors, e.g. LEPs are not permitted to fund work in the NHS, which is a key collaborator in health innovation; • A lack of awareness of the North's innovation assets and strengths among businesses based in the North means that they are not exploiting the innovation potential in the North; • There are pockets of excellence, where cross-sector and/or cross-LEP collaboration is occurring, but the good practice is not shared across sectors or geographies; • A lack of expert leadership on innovation at the level of the North has ensured these challenges have not yet been tackled successfully.
The Missing £4 Billion: Making R&D work for the whole UK by Nesta, 2020	• The UK's overall R&D intensity is low, at 1.66% ,compared to the OECD average of 2.37%. • Regions with relatively high ratios of business spending on R&D per resident to government, university and charity spending on

	R&D per resident include the East of England, South East and South West; the West and East Midlands, the North West and Northern Ireland. • Regions with relatively low ratios of business spending on R&D per resident to government, university and charity spending on R&D per resident include London, Scotland, Wales, Yorkshire and the Humber, and the North East.
Understanding [West and North Yorkshire's] Innovation Capacity, Capability and Potential by RSM, 2019	• West and North Yorkshire's performance and the key factors which underpin a competitive innovation ecosystem are broadly comparable with other LEPs in the North and East Midlands • However regions such as Oxfordshire demonstrate much stronger knowledge, talent and place assets and these are being levered to generate higher levels of productivity than in West and North Yorkshire. • Although the number of innovation active businesses in the region above the national average, the report notes a lack of correlation between high levels of innovation active businesses and subsequent innovation and productivity metrics. • Most innovation within the region is perceived to be incremental or differential, and although businesses are innovating, it is not radical or strategic innovation which will deliver a step change in individual business performance and wider impacts on competitors or suppliers. • Businesses in the region are more likely to be engaged in adopting or improving technology, processes and services rather than new goods, products or knowledge transfer. • The reason for this may be partly attributable to the nature of the business base i.e. a high proportion of SMEs and few OEMs/tier one businesses, but also from low levels of innovation capacity within businesses and a lack of understanding as to what innovation is and how it can be used. • Key drivers identified by stakeholders included within and cross-sector communication, and the importance of external networks and partnerships. However, 43% of businesses were found not to engage with an external partner when innovating. • Only a minority of businesses within the region have a dedicated R&D budget. • Stakeholders also suggested that the regions HEI assets are underutilised, particularly their national and international connections and ability to attract funding and investment, including for physical infrastructure and equipment

Digital Health Sector Report in Yorkshire and the Humber by Perspective Economics	• Yorkshire and the Humber is a nationally significant location for med-tech and digital health businesses and has recognised expertise in digital health sub-sectors such as data services and provider communications. • The region benefits from an already close-knit health-tech eco-system, however findings from the industry survey and other recent studies suggest further scope to facilitate collaboration at various levels – between industry and academia; between industry, academia and clinical expertise; within and between med-tech businesses; and across complementary sectors. • The scale of employment and employment growth demonstrated via this study, particularly among digital health businesses in Leeds, and findings from the industry survey regarding current and future skills needs point to a genuine need for talent and skills development.
Planning for a Step Change: Informing where the North West should focus innovation to drive up Productivity by Hatch Regeneris	• While the Cheshire and Warrington LEP region has the highest Research and Development (R&D) intensity of the North West LEPs, and is among the most productive LEP regions in England, the four other North West LEP region are significantly further behind the England averages on both R&D intensity and productivity. • North West organisations were awarded 5.8% of Innovate UK funding streams funding, compared to the region's 9.7% share of UK businesses and 11.8% share of UK expenditure on R&D by businesses. • Universities are important enablers of innovation, and North West universities have received proportionally more funding than universities as a group have nationally.
Identifying Potential Growth Centres across Great Britain by the Connected Places Catapult and Centre for Cities, 2020	• The report only looked at large urban areas, not rural or more dispersed industrial areas. It ranked them on 6 categories: patents, trademarks, university innovation, business innovation, skills & spillovers, and infrastructure. It found two Northern cities in the top 30%: Leeds and Manchester. • Hull, York, Liverpool and Warrington also featured in the top 50% (as did Blackpool, although this appears to be a typo) • Newcastle, Wakefield, Sunderland, Sheffield, Middlesbrough, Bradford, Barnsley, Blackburn, Doncaster, Preston, Wigan, Burnley, and Huddersfield were all in the bottom 50%, although many were still ranked "strong" on at least one of the six measures.

	• York was the only Northern city ranked strongly for patents. Leeds, Manchester, Warrington, Blackburn, and Huddersfield scored highly on Trademarks, reflecting a relative Northern strength. • Leeds, Manchester, York, Liverpool, Newcastle and Sheffield all scored highly on University Innovation, against, representing a relative Northern strength, however only Manchester and Burnley were rated as strong on Business Innovation. • The skills & spillover and infrastructure metrics were more esoteric in nature. Larger Northern cities tended to score well on the former, whereas only Leeds was rated as strong on infrastructure.
Agglomeration and Clustering Research by Arup, 2019	• Five key types of places can be identified in the North based on their economic and demographic characteristics. These cover most of the North. • The economic geography of the North is complex with clusters of economic activity located both inside and outside of large conurbations covering both traditional and advanced industries. • Transformational places are those higher than average productive places across the North, which do not form part of a large conurbation. They tend to have a high share of employment in advanced manufacturing. They are strongly clustered south of Manchester and Liverpool and in the Cheshire region, as well as north of Hull. • Industrial places reflect those areas working on traditional manufacturing industries, with a lower productivity than the average for the North. These are located southeast of Sheffield, Carlisle, and in the wider Newcastle area.
North East Productivity Review by Cambridge Econometrics and Steer, 2019	• In 2017, business expenditure on R&D in the North East region was £384m, equivalent to 1.8% of the England total (2.1% when excluding London)[4]. This is equivalent to £1.45m R&D expenditure per 10,000 adult population – compared to £4m at the England excluding London level[5]. • Only 42% of enterprises in the North East region engaged in innovation activity between 2014 and 2016, seven percentage points lower than the national average and ranked last among regions in England[6]

[4] ONS, Business enterprise research and development, UK: 2017.

[5] According to 2017 population data by Nomis.

[6] UK Innovation Survey (2017)

	• 19% of firms in the North East LEP area reported to have introduced new or significantly improved processes in the period 2012-14 (5^{th} highest out of the then 39 LEP areas) [7], • Between 2008-12, there were 160 patents registered per 1m residents, approximately 7 times lower than the count for the South East • the North East has significant clusters in healthcare-related fields, such as ageing, pharmaceuticals (particularly biopharmaceuticals), genomics and precision medicine, as well as an emerging cluster in healthcare photonics. • Although the North East sees strong educational outcomes by the North East LEP schools, Higher and Further Education institutions, the area has fewer (in relative terms) higher-skilled workers than in other parts of the UK – 32% compared to 36%, and more (in relative terms) of the working age population with low or no qualifications – 9% compared to 8% • The North East LEP area has a small (in relative terms) private sector economy, measured by low business and job densities in the private sector, with 43.7 businesses born per 10,000 adults in the North East LEP compared to 65.1 in England excluding London • 9.6% of managers in in the North East LEP are not fully proficient in their role, compared to 7.6% in England excluding London • Although the Tyne and Wear Metro provides good inter-urban connectivity within the LEP Area, the North East has a relatively peripheral location within the UK, with long transport times to the majority of UK cities
Innovation in the Humber; transforming the Region's Innovation Capacity through a Local Industrial Strategy by Hull University Business School, 2018	• Offshore energy is identified as the key Humber asset for which the local research, innovation and infrastructure offer is strong in a national context. • Analysis of Innovate UK data from 2004 to 2017 shows the Humber performing below the rest of the Yorkshire & Humber (Y&H) region and the UK as a whole in terms of average project values. • The project carries out a number of case studies that identify "uncaptured" innovation, in both manufacturing and service firms. • Key firms that carry out research and innovation locally include RB, Smith and Nephew, Invidior, Croda, Saltend Chemicals, Phillips 66, British Steel, Novartis, Siemens, KCOM, Sonoco, Vertual, and the centre for Digital Innovation.

[7] Enterprise Research Centre, Benchmarking local innovation – the innovation geography of England: 2017.

	• The importance of the University of Hull to the Humber innovation ecosystem is also highlighted.
Innovation and Global Competitiveness Research Summary part of the greater Manchester Independent Prosperity Review, 2019	• Analysis of the Greater Manchester Business Survey found that innovative firms were more likely to be higher productive firms, and that innovative firms exist in all sectors of the Greater Manchester economy • Greater Manchester has a diverse business base and sophisticated mix of industries and supply chains. It is the most diverse city region in the UK in terms of businesses and jobs, according to the Krugman Specialisation Index. • In an analysis of papers published in peer-reviewed journals, Greater Manchester ranks top 10 globally in five scientific fields: ontology (computer science), design methods, residual stress (material science), qualitative research, and ageing. • Analysis of Meetup and Eventbrite data positions Manchester second, only behind London, for events in important sectors/themes such as digital, energy, fintech, creative and manufacturing. • The SIA identifies two globally competitive areas within the city region's breadth of offer: Health Innovation and Advanced Materials. • Greater Manchester benefits from four universities with main campuses in the city region (University of Manchester, Manchester Metropolitan University, University of Salford and University of Bolton) with over 96,000 students. • There are fewer high performing businesses than the national average in GM engaged in leading-edge R&D, collaboration and leadership i.e. - 'new to market' activities. • Greater Manchester's R&D spend as a proportion of Gross Value Added (GVA) stands at just 0.96%.29 In the context of the Government's commitment to raise total research and development investment to 2.4% of Gross Domestic Product (GDP) by 2027 the city region is clearly lagging behind and is in the bottom ten equivalent areas in the UK. • The Greater Manchester Business Survey revealed that almost one in five (18%) of firms had experienced barriers to innovation. Lack of finance (8%) is a prominent barrier, along with the cost of new product or service development (6%).
Tees Valley Local Industrial Strategy	• Despite high levels of innovation funding coming into Tees Valley, R&D intensity and business expenditure on R&D is generally low relative to national levels. Local R&D performance reflects – to

	some extent – the branch plant dynamic observed in parts of the Tees Valley economy, a view also expressed by stakeholders; • R&D intensity in the local chemicals and process and advanced manufacturing sectors – key strengths and sector specialism within the Tees Valley economy – has declined in recent years; • Key barriers to innovation at the local level are understood to include: awareness/knowledge of the funding landscape; the cost/time implications of the application process; and issues relating to perceived ineligibility; • The area benefits from a number of key innovation assets that are of national/international significance and align to Tees Valley's key sector strengths. Opportunities to encourage the local business base to better leverage these should be pursued; and • Tees Valley's innovation assets (and the area's approach to innovation generally) are positioned towards the commercialisation end of the innovation spectrum. This provides the opportunity to capture a greater number of spin-out businesses with a more co-ordinated and focused approach.
Lancashire Innovation Plan	• Lancashire has well established and recognised strengths in the Aerospace, Automotive, Energy, Nuclear, Digital, and Health Innovation sectors. • There are strengths in biological sciences, Life Sciences and Healthcare, Advanced Manufacturing and materials, and Digital. • The local HEIs have research strengths in STEM subjects, in particular, Computer Science, Mathematical Science, and General Engineering. • There are translational research centres such as the Engineering Innovation Centre at UCLan, the North West Advanced Manufacturing Research Centre at Samlesbury, and the forthcoming Lancaster Health Innovation Campus. • Graduate retention rates are good in Lancashire, and strong Further and Higher Education provision is starting to show in the improving rates of residents with higher level skills. • Analysis of the IPO patenting data indicates strong intellectual property advances in areas such as Civil Engineering, Mechanical Elements, Medical and Computer Technology, and Thermal Processes.
Sheffield City Region: Global Innovation Corridor by Steer Economic Development, 2019	• Compared to TVB and GM, SCR has a lower proportion of Knowledge Intensive Business Services (KIBS). • Patent applications per 10,000 people (one proxy measure of innovative activity) are comparable to GM but far lower than TVB –

	mainly reflecting a greater propensity to patent in the industrial mix in TVB. • Both universities have built-up strong partnerships with businesses and research that aligns with industrial interests. From a GIC perspective, the University of Sheffield's research excellence in general engineering, architecture, planning and the built environment, civil and construction engineering and mechanical, chemical, aerospace and manufacturing engineering, computer science/informatics are all core competencies. Sheffield-Hallam further strengths competencies in architecture, planning and the built environment. • The University of Sheffield has recently topped the UK rankings for engineering research income – catalysed in particular by the AMRC and Sheffield Hallam is buildingup strong and nationally significant capability in food engineering and health/wellbeing research and innovation. • When benchmarked against Greater Manchester (GM) SCR is only marginally behind GM in many measures (e.g. working age population growth and as a per cent of the population, working age population with NVQ L4+ qualifications, employment rates) and somewhat further behind in GVA per resident, GVA per job, average salary). • Compared to GM the SCR does, however, need to lift its business birth rate and the proportion of business defined as knowledge intensive – two important indicators of productivity potential and innovation capacity
Cumbria Local Industrial Strategy, 2019	• Cumbria has a nationally important concentration of civil nuclear innovation assets (see Figure 6.1), with a large cluster of skilled nuclear engineering workers, accounting for about 25% of the UK's nuclear workforce. World leading research and innovation in nuclear de-commissioning/ environmental clean-up, re-processing, waste management and the use of new technologies in hazardous environments (for instance the use of remote operated vehicles in nuclear de-commissioning) takes place in Cumbria. • Several firms have also developed nuclear based innovations that have been sold throughout the world. Sellafield is, via its Gamechangers programme, engaging with SMEs who can help devise solutions to improve the efficiency and cost effectiveness of de-commissioning work. • Expertise in nuclear submarine building linked to BAE systems, who are leading on the development of virtual ship technology for the design of new submarines and ships.

	• A range of manufacturing firms outside the nuclear sector who are involved in the development and continued innovation of new products to ensure they remain globally competitive. • However, there is limited innovation assets elsewhere outside key businesses; low rates of access to external innovation support; and a weak innovation eco-system overall. • The rate of applications by Cumbria firms for UK innovation grants is low and Cumbria has the lowest recorded share of all employment in "science and technology" sectors of any LEP area or just 5% (excluding health/ life sciences) compared to the average of 11%. In absolute terms the amount of employment and businesses engaged in these broadly defined technology-based sectors is particularly low. Cumbria also recorded one of the lowest rates of patent applications per head of population in England. • With the notable exception of the nuclear sector and the firms that are innovative active, there is a limited innovation "ecosystem" due to the small and dispersed nature of economy and businesses across Cumbria. The nature of the Cumbria economy, spread across a large area and with innovation taking place in small isolated islands means that the linkages between those engaged in innovation within Cumbria are limited.
Cheshire and Warrington LEP Industrial Strategy Evidence Base, 2019	• C&W is generating £5.4bn more every year than if it performed at the UK average. A £30.9bn economy it has grown strongly in recent years, exceeding both the UK and North West (NW) average. Looking at GVA per head, in 2017, C&W produced £33,384 per head of population. This is the highest of all northern LEPs and the fourth highest of all LEPs • Manufacturing in particular is thriving, both growing at a significantly higher rate than across the rest of the UK and most manufacturing heartlands. It is over twice as productive as GB with GVA per job of £171,756. It has the biggest GVA contribution of any sector (£7.7bn) and has a high number of jobs (45,000). C&W has particular strengths in: manufacture of petroleum, chemicals and pharmaceuticals and manufacture of motor vehicles, trailers and semi-trailers. • This is an innovative business environment – high spend on Research and Development (R&D) and most Innovate UK projects funded in key sectors. R&D spend is far higher than the UK average. Importantly, this is driven by private sector investment in R&D with over 93% of the total investment by business. Maintaining this high level, whilst also increasing HEI and public sector R&D spend in the region could be of benefit. • Evidence shows that firms who export tend to be more innovative. C&W is a large exporter, exporting more than the LEP average. It

	has strong links beyond the UK with a high number of foreign owned companies (particularly German and US) and strong trade links with non-EU countries. This is positive for post-Brexit resilience and investment activity.
Liverpool City Region Local Industrial Strategy Evidence base, 2019	• With 57.2% of businesses innovation active, LCR has a higher proportion of businesses engaged in innovation than the UK average, and a similarly high proportion of businesses engage in collaborative innovation (this includes collaboration with other businesses, research institutes, HEIs and government). • The most common innovation activity is that related to new/improved strategic business practices and changes to marketing concepts or strategies • LCR has a low proportion of highly skilled workers (NVQ4+), and a high proportion of residents with no qualifications. A highly skilled population is a key component of a competitive, productive economy. • There are 48,000 active businesses in the Liverpool City Region. Since 2012, our business base has grown each year and at a faster rate than both the North West and the UK. This is driven by a consistently higher business birth rate, reflective of an entrepreneurial culture. • LCR's business density (firms per capita) is the lowest of all LEPs. However, it has the fifth highest proportion of scale-up businesses of all LEPs. • Universities in the Liverpool City Region have the highest relative expenditure on R&D of all North West LEPs, however although business expenditure is higher than that of our HEIs, compared to other LEPs, business expenditure on R&D in the Liverpool City Region is low.

1.3 Key research questions

We structure this report around a set of core questions:

- How does innovation diffusion happen within a geography and how does that knowledge and technology diffuse throughout the economy?
- What are the drivers, enablers, and barriers to these processes?
- What do key indicators tell us about how Northern LEPs perform relative to each other and the rest of the UK?
- What questions do these results raise and how might they be tested to deepen our understanding of the North's innovation landscape?
- How do these results align with or diverge from those of previous studies in this area?

1.4 Summary of methodology

A major differentiating property of our approach to analysing innovation performance in the North and its drivers is that it is explicitly sensitive to spatial variation and conceptualises the economy as a network. That is, we recognise that Northern prosperity is not simply the result of the sum of the performance of sub-regional areas – a perspective that all too often assumes that growth can be achieved by simply replication the strategies of more prosperous peers. Rather, we aim to understand the Northern economy as a complex system. Systems thinking is a set of tools and framework for exploring as systemic wholes and focuses on understanding how factors often considered in isolation are interdependent or interact to produce observed outcomes.[8] In practice, this means focusing on uncovering the functional and spatial links between places and their key drivers to generate insight into economic strengths, weaknesses, and potentials for growth. To do this we employ a two main tools – logic mapping and an analysis of technological and spatial relatedness.

Logic mapping can be applied of almost any system or problem. Logic (or, cognitive) maps are qualitative models of a system, consisting of variables and the causal relationships between those variables[9]. Typically, cognitive maps pertain to how individuals perceive the systems in which they are embedded and how those systems work. However, this approach has been adapted to structure analysis of many forms of data and to make sense of accounts of a problem. When applied to document analysis, it can be used to identify emergent issues, gaps, and contradictions in a cognitive landscape. We derived the logic map depicting key metrics (the innovation model) and drivers, enablers, and barriers from a review of academic and grey literature. Figure 1.4.1 depicts an example of a logic map that we used to guide our own map development.

[8] Byrne, David, and Gill Callaghan (2014) *Complexity Theory and the Social Sciences: The State of the Art*. London: Routledge.

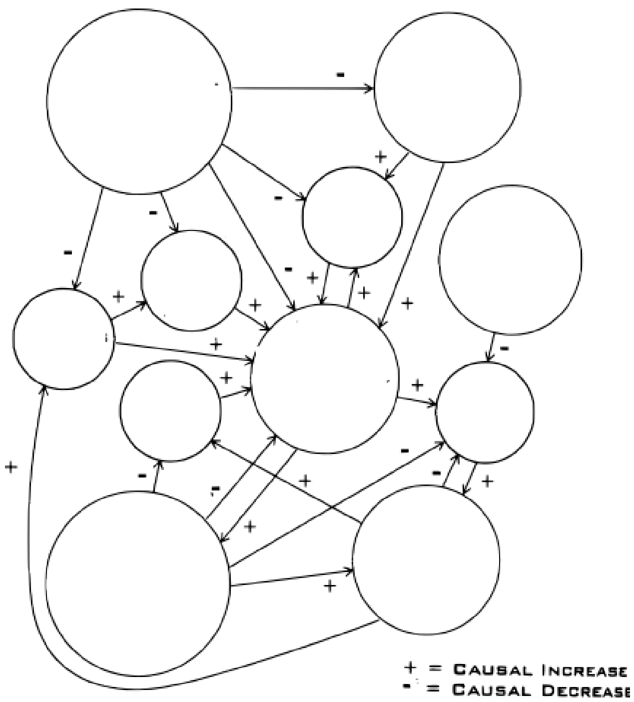
Cairney, Paul (2012). "Complexity Theory in Political Science and Public Policy." *Political Studies Review* 10 (3):346-358.

Meadows, Donella (2008) *Thinking in Systems: A Primer*. White River Junction, VT: Chelsea Green Publishing.

Mitchell, Melanie (2009) *Complexity: A Guided Tour*. Oxford: Oxford University Press.

[9] Özesmi, Uygar, & Özesmi, Stacy L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecological Modelling, 176(1), 43-64. doi:https://doi.org/10.1016/j.ecolmodel.2003.10.027

Figure 1.4.1: Example of a logic map



In addition to providing a conceptual foundation for our analysis of the North's innovation economy the logic map informed the selection of indicators in the dashboard presented in an interim form in section 3. That section also contains early findings from our analysis of technological relatedness.

Analysing **technological relatedness** contributes novel insights with respect to sectoral specialisation, the alignment between capabilities, and potential future growth pathways. We argue that the precise ways in which specific regional economic and knowledge capabilities influence the evolution of local technology trajectories, and thus potential current and future economic prosperity, have not been considered systematically. Essentially, most territorial innovation models apply a top-down approach that employs industry and occupation data to infer from these onto potential knowledge competencies. Typically, these models also engage in a trade-off between detailed case-studies that are difficult to replicate and broader approaches that are neglectful of vital place-specific details. Furthermore, denotations of concentration and specialization are frequently convoluted with little reference to their potential different meanings in spatial and sectoral contexts. In summary, what is currently missing is a territorial innovation model that applies a bottom-up approach where knowledge, the actual source of scientific and technical advancement, is central.

Our model is sensitive to unique place-based properties, and thus pivotal to investigations of technological change and economic growth, but also take into consideration the critical aspects and dynamics of place specific features and network properties. Synthesising these insights with those of the logic map helps to both track and visualise these dynamics in specific geographical contexts. We are constructing the technological relatedness model utilizing the database on novel products and processes of economic value, i.e. patented inventions.

We rely on a variety of data sets and aim to capture the inventive economic structure of sub-regional units within the North[10], determine regional (NUTS2) evolutionary trajectories (regional knowledge spaces)[11], six dimensions of knowledge space network metrics[12], technology life-cycle metrics, relatedness density scores, and re-combination metrics to identify present state, but also future opportunities for related specialisation and diversification in the local knowledge base. We also consider metrics that indicate the 'strength' and 'embeddedness' of public vs. private institutions in the technology knowledge space, including an index of internationalization, i.e. a measure of inter-regional, -national vs. intra-regional co-inventor networks in regard to knowledge sourcing and spillovers. Finally, we include measures of diversification (entry relatedness scores, recombinant knowledge indicators) along with opportunities for specialization in terms of entry and exit. Of particular interest in this analysis will be the identification of existing capabilities or technological expertise vs. future opportunities that are highlighted in the evolutionary model of technological change.

Chapter 2 presents the results of a literature review and develops a logic map. **Chapter 3** then identifies and presents a range of identifiers for each variable, further analysed in **Chapter 4. Chapters 5 and 6** then present further quantitative analysis using patent and Innovate UK funding data, **Chapter 7** presents three case studies, and **Chapter 8** provides final conclusions and recommendations.

[10] Lybbert T. J. and Zolas N. J. (2014) Getting patents and economic data to speak to each other: An 'algorithmic links with probabilities' approach for joint analyses of patenting and economic activity, Research Policy 43(3), 530-542.

[11] This relies on approx. 650 Corporate Patent Classification (CPC) classes in PATSTAT patent documents (1980-2017). See, Kogler, D. F., et al. (2018). "Patent portfolio analysis of cities: statistics and maps of technological inventiveness." European Planning Studies 26(11): 2256-2278 and Kogler, D. F. and A. Whittle (2018). The geography of knowledge creation: technological relatedness and regional smart specialization strategies. Handbook on the Geography of Regions and Territories. A. Paasi, J. Harrison and M. Jones. Cheltenham, Edward Elgar: 153-168.

[12] Lee, C., Kogler, D.F., & Lee, D. (2019). Capturing Information on Technology Convergence, International Collaboration, and Knowledge Flow from Patent Document: A Case of Information and Communication Technology, Information Processing & Management 56(4): 1576-1591. DOI:10.1016/j.ipm.2018.09.007.

2 Explaining Innovation

2.1 The Innovation Process

In this study, we explore the factors that generate innovation and fuel productivity within regional economies. As such we place the process that yields these outcomes at the centre of our logic map. This section outlines the components of the model of the innovation process that we have adopted for this project.

Broadly, innovation can be defined as new practical knowledge.[13] These are ideas that do not merely contribute to the store of human knowledge but that have impact and application. Innovation has also been described as the effective application of processes and products and as the creation and capture of value.[14] This definition encompasses a wide variety of activities. For instance, drawing on the OECD definition adopted by Eurostat, the UK Innovation Survey lists all the following as instances of innovation:

1 The introduction of a new or significantly improved product (good or service) or process.

2 Engagement in innovation projects not yet complete, scaled back, or abandoned.

3 New and significantly improved forms of organisation, business structures or practices, and marketing concepts or strategies.

4 Investment activities in areas such as internal research and development, training, acquisition of external knowledge or machinery and equipment linked to innovation activities.[15]

Collectively, these definitions focus on innovation *outcomes* – new products, new value, new forms of organisation, new practices, etc. However, innovation can also be described as a *process*. Innovation outcomes describe the typical end result of innovation – the 'what' – while innovation processes outline the stages through which those results can be achieved. While public policy typically prioritises innovation outcomes it also recognises the value of understanding and encouraging each element of the processes.

For this project, we adopt a stylised version of an innovation model that depicts the various phases of the innovation process (see Figure 2.1.1). This model includes elements of interrelated processes of idea generation (knowledge creation); implementation, commercialization, and marketing (value creation); and dissemination and adoption (diffusion). Note that this model includes these latter two phases to emphasise that the value of

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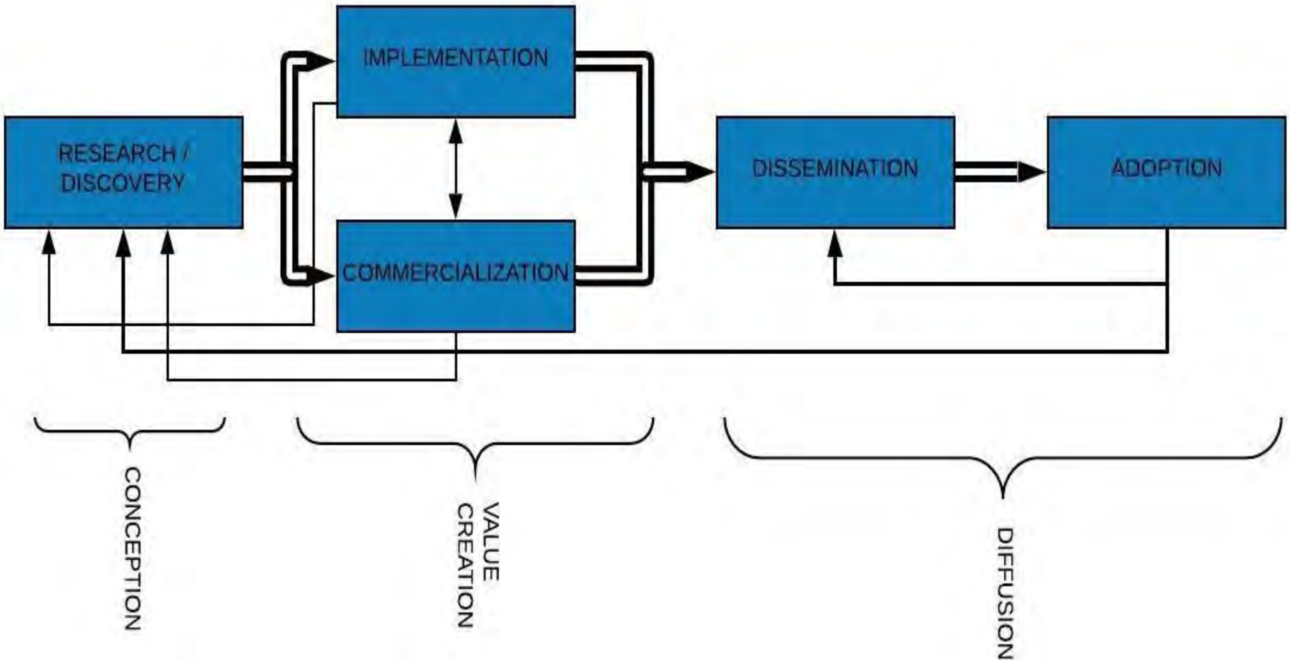
[13] de la Mothe, J., & Paquet, G. (2012). Local and Regional Systems of Innovation. New York: Springer.

[14] Ritala, P., Agouridas, V., Assimakopoulos, D., & Gies, O. (2013). Value creation and capture mechanisms in innovation ecosystems: a comparative case study. International Journal of Technology Management, 63(3-4), 244-267. doi:10.1504/ijtm.2013.056900

[15] BEIS (2020). UK Innovation Survey 2019: Headline Findings Covering the Survey Period 2016-2018. Released 26 March, 2020.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/873740/UKIS_2019_Headlines_Findings.pdf

innovation is multiplied across the economy when it is adopted by other entities. In short, the innovation process does not stop with the internal implementation or external commercialization and marketing of an innovation, but continues once new ideas, processes, practices, or products become a part of the knowledge base.

Figure 2.1.1: Stages in the Innovation Process



We conceptualise the overall process as a *system of processes*. While at first glance this process may appear deceptively linear, we adopt the approach of later generation evolutionary and systems innovation models that stress that innovative outcomes result from complex interactions across a system of linked processes[16]. The thick arrows in Figure 2.1.1 show a general rightward progression from idea to broader adoption within the economy. However, the thinner arrows show some of the interactions, feedback loops, and links that occur between (often non-contiguous) phases.

We describe each of these waypoints in the innovation process in the following section. The central point here is that in conceptualising this process as a system of processes we develop a more nuanced understanding of the stages involved in generating innovation as an outcome. It also permits us to construct a better understanding of how elements of the regional economy – the system within which innovating entities are embedded – contribute to different phases of the process. Scrutinising metrics at each of these stages enables deeper insights into the strengths and weaknesses of the region's economy as well as a better understanding of the systemic factors that influence these processes. We discuss these drivers and enablers of innovation and diffusion later in this section.

[16] See Bathelt, H.; Cohendet, P.; Henn, S.; Simon, L. *The Elgar Companion to Innovation and Knowledge Creation*; Edward Elgar Publishing, 2017.

2.2 Overview of the Innovation Process

Our innovation process model focuses on the five following phases. While we discuss them in turn, it is important to recall that these are interdependent and often occur non-sequentially. Our version of the innovation process model draws heavily on open and interactive models that have evolved since the 1990s.[17] These specifically focus the embeddedness of innovation activities in place, the degree to which innovation relies on integrating internal and external knowledge, and consequently, the value of encouraging and leveraging knowledge flows at not only the idea generation phase but at all phases of the innovation process. As such, in this section we not only define the elements of our innovation model but also begin to draw out key drivers that shape and comprise the system within which innovative activity takes place. In this case, we use LEPs as the territorial frame of reference.

Knowledge creation – the creation of new ideas

Ideas arise when the same person or groups of people become simultaneously aware of a specific problem or opportunity, and the key piece of knowledge required to resolve it. At this point, an idea is formed, that utilises the knowledge and identifies a means of solving the problem or taking advantage of the opportunity. Knowledge creation[18] functions as an umbrella term to capture the diversity of ways that ideas emerge:

Research (e.g. a researcher investigating a specific problem)

Research may be undertaken through a publicly- or part-publicly-funded body, such as a university or research institute, through a private research organisation. It can be undertaken with the intention of commercialising findings (as with pure applied research), for the purpose of a search for fundamental understanding (as with pure basic research), or these two purposes can fuse in fundamental research inspired by future use (Pasteur’s quadrant)[19].

Spontaneous discovery (e.g. ideas from unplanned sources)

Ideas are not always the result of purposive research. Sometimes these occur spontaneously as a result of casual conversation or individual observations. This occurs through the interaction of individuals or firms, in which information about problems and potential solutions is freely shared. Additionally, accidental discovery can occur through a process of tinkering - when someone plays around with a product or a technology with no goal, neither for enhancement of meaning nor for practicality[20].

There is, of course, a large amount of overlap between the two; a researcher studying a particular problem might stumble across the solution through an unexpected interaction or may obtain knowledge that provides someone else with a key idea, through interaction. The flow of new ideas is the central driving force of innovation.

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[17] Cohendet, P. and L. Simon (2017). Concepts and models of innovation. The Elgar Companion to Innovation and Knowledge Creation. H. Bathelt, P. Cohendet, S. Henn and S. Laurent. Cheltenham, Edward Elgar: 33-55.

[18] See Cantisani, A. (2006). "Technological innovation processes revisited." Technovation 26(11): 1294-1301.

[19] Stokes, D. (1997). Pasteur's Quadrant: Basic Science and Technological Innovation. Washington, DC, Brookings Institution Press.

[20] Norman, D. A. and R. Verganti (2014). "Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change." Design Issues 30(1): 78-96.

Drivers of Knowledge creation

Key drivers within a LEP area[21] are the presence and level of **knowledge base**, which is indicative of research activity, within the region whether public or private. While innovators are certainly not limited to localised knowledge in this process, the depth and richness of the proximate knowledge base increases the potential for innovative inspiration. **Innovation culture** will shape propensity to engage in knowledge searches of various kinds. Discovery and research occur best through the interaction of individuals or firms in which information about problems and potential solutions is freely shared. Thus, the **level of interaction across networks** both within and between regional ecosystems is a key driver here. Not only will interaction across networks facilitate access to the broader knowledge base, but the serendipitous encounters, buzz, and knowledge 'in the air' can provide an inspirational spark for innovation. There is also evidence that ecosystems with higher levels of **technological relatedness** and denser configurations of workers with specific skills, an element of a region's **human capital profile,** experience higher levels of coincidental interaction and subsequent flows of spontaneous discovery.

Value creation – the execution of new ideas

The exercise of turning initial ideas into products, processes, or practices within the innovation process can be described as value creation. This phase transforms what had been merely an idea into an applicable form through execution, (experimental) development, testing, engineering, and production (e.g.). The process of implementation may be simple and straightforward, or it may be difficult, time-consuming, and required several subsequent periods of discovery before coming to fruition. Depending on the organisational setting and nature of the idea, the value creation process may be done internally to an organisation or involve external partnerships. We conceptualise these processes as having two potential (and not mutually exclusive) results:

Implementation

When innovations are developed for internal use their goal is ultimately the implementation within firm workflows. Whether the innovation consists of an improvement to a piece of production machinery or accounting practice it begins to generate value at the point at which it is integrated into the business. Although the innovations described here might be meant for internal use and to generate competitive advantage for the firm, this does not preclude its potential commercialisation or diffusion through non-market mechanisms.

Commercial-isation

Knowledge or technology commercialisation can be generally described as an actor's deliberate transmission of knowledge assets to another independent actor, involving a contractual obligation for compensation in monetary or non-monetary terms[22] or for non-commercial exploitation for social benefit. As we allude to above, the actual transfer of the knowledge assets constitutes only a final step of the value creation process.

Drivers of Value Creation

Within the LEP geography, the flow of both local and external ideas, embodied in **levels of interaction across networks**, is a key determinant of the level of subsequent implementations. Characteristics of the **knowledge base** will also shape firms' ability to implement or commercialise their innovations.

[21] Within this report, we use "LEP" to refer to the structure of governance, and "LEP area" or "LEP geography" to refer to the associated territory and the actors within it

[22] Lichtenthaler, U. (2005). "External commercialization of knowledge: Review and research agenda." International Journal of Management Reviews 7(4): 231-255.

Technological relatedness tends to increase both implementation and commercialisation as evidenced by its positive correlation with indicators like patent applications. A strong **culture of innovation** will also tend to drive ideas through the development process both at the individual and organisational level, while the **human capital** profile determines the availability of both the technical and managerial skillsets required for effective value creation.

Diffusion – the transmission and adoption of new ideas

In this project, we are defining diffusion, generally, as an umbrella terms for the stage of innovation that encompasses the knowledge or technology dissemination (transmission) and adoption (receiving) phases. Following the initial implementation or commercialisation phase, this point in the process begins as the innovation exits the creating entity and becomes more widely available.

Dissemination

We use the term dissemination to refer to the action of spreading the invention widely, whether formally through the market or more tacitly through social networks. From a policy perspective, developing an environment fertile for knowledge circulation so that firms are aware of opportunities for innovation adoption is as important as ensuring that firms are open to incorporating available innovations into their offerings and processes. For instance, a region rich in knowledge flows will tend to export it in global pipelines if it is inappropriate to its sectoral profile, or where firms lack the capacity to integrate it into their production or processes, and may fail to capture and embed locally produced innovation (diffusion without adoption). Similarly, firms may conduct internal R&D and may thus contribute positively to innovation activity figures for the broader economy but may not engage in local partnerships or knowledge exchange relationships that would optimise innovation diffusion (adoption and creation without diffusion). These are, of course, only two permutations on a spectrum of possible outcomes.

Adoption

The adoption of innovation is a process that results in the assimilation of a product, process, or practice that is new to the adopting actor[23]. This process is internal to a firm but relies on access to innovation and knowledge diffusion (or knowledge transfer) within the economy. Economies require both firms that are receptive to adopting innovation as well as the mechanisms necessary to effectively transmit information about available innovations.

Drivers of Diffusion

Dissemination may occur through commercial advertising, market mechanisms or formally or informally across informally across networks. The decision to adopt a new technology is driven by the usefulness of the solution to the particular firm. Key drivers for both are **levels of interaction across networks,** and **technological relatedness**. In addition to markets, networks provide the conduits through which information about the innovation disseminates. Information about innovations is likely to circulate more effectively in environments with higher degrees of technological relatedness. Diffusion affects the **knowledge base** to the extent that when innovations are disseminated, they add to the region's stock of public knowledge. **Human**

[23] Damanpour, F. and M. Schneider (2008). "Characteristics of Innovation and Innovation Adoption in Public Organizations: Assessing the Role of Managers." Journal of Public Administration Research and Theory 19(3): 495-522.

capital profiles affect the stock of management and technical skills that contribute to higher levels of innovation adoption.[24]

We revisit these drivers and their influence on the phases of the innovation process in Section 2.4. Before turning to the foundations of the logic map, we provide some more detail about the locus and levels of innovation that we use as our central points of reference in this project.

2.3 Locus and Level of Innovation

Innovation is a multidimensional and multiscalar process. That is, it can emerge from and take place within a variety of different contexts – from the individual running a microbusiness to international mega-corporations. Innovations can be transmitted through formal structures such as firms or research partnerships and through informal networks. Propensity for innovation can also be discussed at a variety of scales – from the individual to the whole economy. While most studies tend to focus in on specific actors, scales, or structures they all coexist in complex ways. For instance, we can speak equally about the propensity of a region to innovate and understand that characteristics of the regional innovation ecosystem shape the innovation decisions of entities within it. In this section, we acknowledge the complexity of the systems that we are studying but also lay out our scope of interest. We focus specifically on the concepts of locus, level and scale of innovation.

Locus of innovation

While there are different interpretations of the term, we use locus to refer to the different vectors and mechanisms of the innovation process through which innovation might flow. Table 2.3.1[25] plots the phases of the innovation process against a few possible loci of innovation and knowledge transmission.

[24] We could have conceptualised diffusion as simply a return to 'beginning' of the innovation process model to begin a new phase of research and value creation with the same technology in a different enterprise. The processes are roughly parallel, and to a large extent, difficult to separate at a conceptual level. For instance, distinguishing between a firm learning of (disseminated) research and implementing an internal innovation, and a firm learning of a new innovation from another actor that they then adopt, is a matter of perspective. We opt to treat the diffusion phase separately in this study in order to explore more fully the conditions under which firms in a region will be more open to adopting new ideas and technologies as a distinctive process from typical research and development arcs.

[25] For visual clarity, some of the dimensions of our matrix have been suppressed – for example we do not distinguish here between product and process innovation (in so much as a clear separation exists), or wider organisational settings, but focus on considering what different stages of the innovation process look like when practiced through one of the three *canonical organisational forms* (markets, networks and hierarchies).

Table 2.3.1: Conceptualising the stages of innovation when practised through various organisational forms

Stages of innovation vs. Locus of innovation	Via the commercial market system	Within organisations	Across informal networks
Knowledge creation – the creation of new ideas	Knowledge is obtained through commercial transaction	Knowledge is obtained through an internal research process	Knowledge is obtained through informal networks
Value creation – the implementation of new ideas	Idea developed as a commercial concern	Idea developed and integrated as part of an internal development process	Idea developed through informal collaboration
Diffusion – the transmission and adoption of new ideas	Transmission and adoption of new idea as a commercial product	Idea imitated or adapted by users within the organisation – broader spillovers possible.	Transmission of idea to other organisations through networks

Significantly, while the central column ("within organisations") read top to bottom represents a closed innovation process innovation does not necessarily proceed vertically through a single column. Other processes are more open.[26] For instance, a firm can obtain knowledge through market mechanisms, adopt it in the value creation phase, and then have that practice disseminated through informal networks to others in the economy (proceeding in a diagonal from top left to bottom right). Similarly, different aspects of the innovation process can take different paths simultaneously. The broad point here is that there are many paths through the process, that can splinter and feedback and, as a result, flow through and germinate in all sorts of loci. Although we acknowledge that each locus, and each path, has its own advantages and challenges, and that these will vary across a number of dimensions, we cannot explore each one within the boundaries of this project.

Level and scale of innovation

From a policy perspective, it is important to understand the difference between levels and scales of innovation. Level of innovation refers to the difference between individual, group, and firm processes. The source of innovations can be traced to agents acting at any one of these *levels*. By contrast, innovation output can be studied and measured at any *scale* from the individual to the global economy. Scale, for our purposes, refers to the boundaries of the scope of inquiry. Importantly, the degree of innovative activity measurable at any scale is the product of the collective decisions and activities of agents at the

[26] Crossan, M. M. and M. Apaydin (2010). "A Multi-Dimensional Framework of Organizational Innovation: A Systematic Review of the Literature." Journal of Management Studies 47(6): 1154-1191.

various different levels within that geography. In this study, we are interested primarily in innovation at the scale of Local Economic Partnerships (LEPs) within the North of England.

LEPs were created by the Department of Business, Innovation, and Skills (BIS) in 2011 as successor to Regional Development Agencies. There are currently 38 LEPs active across England, 11 of which are located in the North. These organisations play an important role in local economic development through their involvement in developing and delivering programmes around housing and infrastructure, sectoral deals, local industrial strategies, strategic economic planning, skills, and more. In these capacities, they both contain and shape their own local innovation ecosystems. As such, these are useful geographies at which to understand and compare innovation patterns and processes. However, it is important to acknowledge that while we can point to localised factors that influence the innovation process the actors involved in these processes are themselves embedded in multiple and overlapping ecosystems functioning at different scales.[27] The concept of nested scales represents this idea that innovation is affected by policies, institutions, networks, and environments shaped by and within systems operating at different scales. Identifying and disentangling the effect of each of these layers is nearly impossible but acknowledging their existence is helpful for guiding analysis and policy recommendations. In practice, nested scales imply that the relative prosperity and productivity of any functional geography, and its corresponding ability to generate, combine and utilise innovative knowledge and technologies, depends on both its ability to integrate its own fundamental component parts (be they different clusters, sectors, or sub-geographies) in a coherent and synergistic manner, and its ability to find a productive niche within wider regional, national and international networks.

As such, LEP areas require a strong and functional *internal* ecosystem that encourages synergistic engagement both between internal components, and between those components and the wider network of *external* actors and systems. This study focuses specifically on the levers that LEPs and other policy makers can influence within their local ecosystems but in the understanding that many of these also have effects on, and should be activated in recognition of, external interfaces. Most of the drivers that are considered in this project are specifically local in nature; the *local* knowledge base, the *local* innovation culture, for example. However, the extent to which actors within LEP geographies are positioned to interact with external networks is also considered, particularly when considering the importance of interaction across networks.

2.4 Drivers, Enablers and Barriers

The next stage in the process is to identify the factors that influence the stages and pathways of this process, either collectively or individually. For the purposes of this study, we identify three types of influences on innovation and diffusion processes. We outline these below.

[27] Bradford, N. and A. Bramwell (2016). Regional economic development: Institutions, innovation, and policy. Handbook on Geographies of Innovation. R. Shearmu, C. Carrincazeaux and D. Doloreux. Cheltenham, Edward Elgar: 292-308.

1 **Drivers** – factors that (theory suggests) directly influence the innovation/diffusion process

2 **Enabling factors** – factors that influence the presence or effectiveness of key driving factors in impacting the innovation and diffusion processes

3 **Barriers** – are factors (either drivers or enablers) that can, under certain circumstances, have negative effects on innovation and/or diffusions processes. This can either be by its absence or weakness (for instance of specific skillsets) or by having multiple effects (for instance, strong IP policies protect innovation, but they can also discourage certain kinds of incremental innovations). Because they are based on drivers and enablers, they do not require separate categorisation.

From our exploration into the innovation/diffusion process and preliminary review of the literature, we have identified a preliminary list of drivers and a set of provisional indicators that we have chosen to focus on because they were most prominent in the literature reviewed and most closely aligned with the objectives of the project. In the following section, we summarise the drivers, how we are operationalising them, and their expected impacts. We also note the relationships between them, as they exhibit some important interaction effects that are critical to our understanding of system dynamics.

Table 2.4.1. Key Drivers and Enablers to be included in the logic map

Key Drivers
Depth and breadth of knowledge pool
Technological relatedness
Human capital profile
Levels of interaction across networks
Innovation culture

Key Enablers
Sectoral structure
Business base characteristics
Strength and engagement of local anchor institutions
Quality of place
Connectivity
Support systems

Drivers

We will now discuss in more detail each of the five key drivers identified; for each driver, we will provide a definition, some initial thoughts about operationalisation and measurement, and a discussion about the interlinks with elements of the innovation process, other drivers, and enablers.

Depth and openness of the endogenous knowledge base

Although knowledge can come from many different sources, in this driver we are principally concerned with the pool of regionally endogenous (localised) knowledge that forms the base from which individuals and firms inspire and develop new ideas. Rather intuitively, a wealth of research suggests that depth of regional knowledge bases is closely correlated with innovative activity.[28]

We define the regional knowledge base as the store of information that is produced by and embedded within the knowledge-generating organisations

[28] See, for instance, Asheim, B. T. and L. Coenen (2005). "Knowledge bases and regional innovation systems: Comparing Nordic clusters." Research Policy 34(8): 1173-1190

and firms within the region. The types of knowledge that emerge and anchor a region are strongly dependent on, on the higher education side, the *strength and engagement of local anchor institutions* – which includes universities, labs, and other non-firm knowledge facilities. The regional knowledge base produced by firms is largely a product of the *sectoral structure* of the economy.

Research and development (R&D) spending across various sectors of the economy is frequently used as a measure of the knowledge base. Various metrics, including business enterprise research and development (BERD), higher education research and development (HERD), and, more generally, gross domestic expenditure on research and development (GERD) provide comparative insights into regional knowledge bases. While these provide an appropriate measure of stocks of regional knowledge, they are not as effective regional knowledge assets if large proportions are privileged and access is limited. Therefore, it is important to consider degrees of knowledge accessibility or openness as potential drivers of, or barriers to, innovative activity. Here is one of several instances where interaction with key drivers and enablers becomes apparent. Knowledge accessibility is partly a function of opportunities for intra-regional interaction and associated with the *structure and interaction across networks* as well as other factors such *physical and digital connectivity.*[29] Knowledge bases are also embedded in the people that populate the region and so there are strong connections between these metrics and the *human capital profile* of the region. Finally, the innovative potential of the knowledge base will also depend in large part on *technological and industrial relatedness,* itself related to *sectoral structure*, that encourages recombinant innovation.[30] Finally, the degree of knowledge production in a region will also likely be related to *support structures*, particularly in the form of public research funding.

Other considerations that we are attempting to include in our model is the fact that the depth and accessibility of the knowledge base is likely to be uneven across industries, and possibly across internal geographies (see again, *sectoral structure*). Also, the types of knowledge required differ at different stages of innovation and diffusion processes[31] so, it will be important to consider those dynamics as well.

Technological and industrial relatedness

As the previous driver suggests, the mere existence of a deep knowledge base is not enough to effectively drive strong innovation and diffusion processes. Rather, recent scholarship suggests that regions with industries that have a diversity of industries (and products) that are technologically and cognitively related exhibit increased innovation activity.[32] Rather than focus

[29] Andersson, M. and C. Karlsson (2007). "Knowledge in Regional Economic Growth—The Role of Knowledge Accessibility." Industry and Innovation 14(2): 129-149.

[30] Antonelli, C., Krafft, J., & Quatraro, F. (2010). Recombinant knowledge and growth: The case of ICTs. *Structural Change and Economic Dynamics, 21*(1), 50-69.

[31] Davids, M. and K. Frenken (2018). "Proximity, knowledge base and the innovation process: towards an integrated framework." Regional Studies 52(1): 23-34.

[32] Aarstad, J., et al. (2016). "Related and unrelated variety as regional drivers of enterprise productivity and innovation: A multilevel study." Research Policy 45(4): 844-856. See also, Asheim, B. T., et al. (2011). "Constructing Regional Advantage: Platform Policies Based on Related Variety and Differentiated Knowledge Bases." Regional Studies 45(7): 893-904.

exclusively on specialisation, regions are urged to aim for an optimal level of related variety across industries, skills, and, ultimately innovative output.

The theory of related variety is that a degree of technological diversification within economies is supportive of innovation if it is related (similar), whether in a knowledge base, technological, or market sense. This builds on the concept of recombinant knowledge, which posits that some groups of knowledge and artefacts are easier to combine than others.[33] Measuring and comparing relatedness across and within regions is somewhat difficult, but Kogler et al. have developed a methodology based on patent data and regional technology profiles.[34] This methodology will enable us to identify the degree to which knowledge and industries are cognitively proximate and estimate potential for innovative activity. Obviously, this driver depends in large part on the profile of the *regional knowledge base* and *sectoral structures*. While transmission of knowledge between related industries is more likely it is not guaranteed, and so the influence of relatedness also relies on factors related to *network engagement* and *digital and physical connectivity*. Significantly, the concept of relatedness has been applied across a variety of different aspects of the economy including aspects of *human capital*, including skills profiles.[35]

Human capital profile

So much of what makes a region successful is embodied in the people that make things happen. A region's human capital - collective skills, knowledge, or other intangible assets that individuals possess that can be used to create economic value for the themselves, their employers, or their community – is an incredibly important driver of innovation and diffusion processes. This type of capital is associated not only with knowledge and skills but also creativity and innovation capacity.[36] Regional human capital is often measured in terms of the educational attainment of the workforce, and this remains a useful metric through which to understand the mix of skills available in the economy. This attainment level will, in part, be related to factors such as the *strength of anchor institutions* such as colleges and universities. However, much as with the knowledge base driver the important impacts of the human dimension of economy is rife with nuance. For instance, since previous work experience invests individuals with important tools and tacit knowledge acquired outside of educational institutions the stock of experienced workers across skills profiles provides important insights into the innovative potential of a region.[37] In our logic map, human capital profile influences nearly every phase of the innovation process to the extent that it measures the aggregation of skills that decision makers themselves possess (and, therefore shapes the decisions of individual actors all along the process) but also determines the human

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[33] Content, J., & Frenken, K. (2016). Related variety and economic development: a literature review. *European Planning Studies, 24*(12), 2097-2112. doi:10.1080/09654313.2016.1246517

[34] Kogler, D. F., et al. (2013). "Mapping Knowledge Space and Technological Relatedness in US Cities." European Planning Studies 21(9): 1374-1391.

[35] Rodríguez-Pose, A. and N. Lee (2020). "Hipsters vs. geeks? Creative workers, STEM and innovation in US cities." Cities 100: 102653. See also, Solheim, M. C. W., et al. (2020). "Collected worker experiences and the novelty content of innovation." Research Policy 49(1): 103856.

[36] Pasban, M. and S. H. Nojedeh (2016). "A Review of the Role of Human Capital in the Organization." Procedia - Social and Behavioral Sciences 230: 249-253.

[37] Solheim, M. C. W., et al. (2020). "Collected worker experiences and the novelty content of innovation." Research Policy 49(1): 103856.

resources that they have at their disposal to allocate to innovation development.

Here, again, the close interaction between drivers and enablers is apparent. One of the advantages of a deep and diverse labour force is the potential that it engenders for knowledge spillovers that can kickstart and sustain innovation and diffusion processes. Therefore, we are interested in not only the mix of workforce education and experience but the opportunities that individuals have for interaction.[38] This is a function of factors such as areas of high skilled employment density, the robustness and *engagement across networks* and also forms of *physical and digital connectivity* and *qualities of place* that promote interpersonal interaction. While in open economies the makeup of the workforce is also influenced in part by exogenous factors such as immigration policies, which are outside the scope of this study, we believe that these are captured by enabling factors such as regional attractiveness to talent that are affected by things such as *sectoral mix, business base characteristics,* and *qualities of place*. Finally, different types of skills are required at different points in the innovation and diffusion processes (as was the case with knowledge) - even within the same firm or industry – which again speaks to the need to understand what an optimal human capital profile should look like.

Levels of interaction across networks

It is widely accepted that social, civic, and business networks have a positive impact on innovative activity, and literature on economic development and innovation has spawned a rich literature that explores the catalytic and transformative power of these invisible forces within regions. The capacity for networking is seen as essential for tapping into the shared intelligence of both the individual firm organisation, as well as a collectivity of firms within a given geographic space. In contrast to the more conventional forms of inter-firm relations — markets and hierarchies — this alternative form of resource allocation is characterized by transactions that “occur neither through discrete exchanges nor by administrative fiat, but through networks of individuals engaged in reciprocal, preferential, mutually supportive actions”.[39]

The interaction between diverse groups of actors participating in networks takes the form of sharing information, knowledge and perspectives, as well as coordinating their activities to achieve and implement more effective solutions to problems — particularly in situations where the solutions lie beyond the capacity of any one party to achieve. In addition to these critical coordinative functions, in innovation and diffusion processes networks are important knowledge transmission functions and influence knowledge spillovers.[40] They also connect actors with the information, advice, and resources.[41] Networks that function at the regional scale act as bridges between regional resources

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[38] Messinis, G. and A. D. Ahmed (2013). "Cognitive skills, innovation and technology diffusion." Economic Modelling 30: 565-578.

[39] Powell, Walter W. 1990. “Neither Market Nor Hierarchy: Network Forms of Organization,” eds Barry M. Staw and L.L. Cummings. In *Research in Organization Behaviour*. 12. Greenwich, Conn.: JAI Press, 295–336.

[40]Nelles, J. and D. A. Wolfe (Forthcoming). Urban Governance and Civic Capital: A Survey of an Evolving Concept. Munk Center for International Relations, University of Toronto, Innovation Policy Lab.

[41] Christopherson, S., et al. (2008). "Innovation, networks and knowledge exchange." Cambridge Journal of Regions, Economy and Society 1(2): 165-173.

(knowledge, labour etc) and regional innovation processes.[42] Networks emerge and knowledge percolates though iterated interpersonal or business interaction in physical or virtual spaces (such as social networks or using digital communications).

Networks are notoriously difficult to measure and typically requires in-depth qualitative research to determine their extents, contours, and influence.[43] We intend to use data on industry organisation membership and, to the extent that it is available, frequency of business and industry networking events/conference. Measures such as the spatial density and clustering of workers and industries can also provide an indication that there may be vibrant networks at play.

The prevalence of networks has an important influence on all elements of the innovation and diffusion cycles. Particularly those, like the invention and dissemination stages, where knowledge transmission mechanisms are especially important. Similarly, networks have strong influences on many of the drivers and enablers that we've identified, including *relatedness*, *entrepreneurial activity*, and *human capital profiles*. It also has an important influence on the effectiveness of *support structures* such as incubators and accelerators, affects quality of place, and provide important conduits of knowledge.

Innovation culture

Innovation culture describes the collection of attitudes, outlooks, norms, and beliefs that inform the practice of innovation in regional economies. A broad consensus has emerged that the culture of a place plays an important role in the innovation process.[44] Within regions, these cultures develop over time and through a variety of mechanisms, a process often anchored by and international firm or a leading university and disseminates across the region through spinoffs and movement of workers from the major anchor organization to other firms. Saxenian's seminal study of the Silicon Valley and Route 128 in Boston highlights the power of (in this case, corporate) cultures to shape entire regions.[45]

Broadly, innovation culture encompasses the social values and norms that promote risk-taking, creativity, collaboration, knowledge exchange, and openness that are critical for innovation success.[46] For instance, innovation

42 Rutten, R. and F. Boekema (2007). "Regional social capital: Embeddedness, innovation networks and regional economic development." Technological Forecasting and Social Change 74(9): 1834-1846.

43 Doh, S. and Z. J. Acs (2010). "Innovation and Social Capital: A Cross-Country Investigation." Industry and Innovation 17(3): 241-262.

44 Spigel, B. The cultural embeddedness of regional innovation: A Bourdieuian perspective. Handbook on the Geographies of Innovation. R. Shearmur, C. Carrincazeaux and D. Doloreux. Cheltenham, Edward Elgar: 88-99.

45 See, Saxenian, A. (1994). Regional Advantage: Culture and Competition in Silicon Valley and Route 128. Cambridge, MA, Harvard University Press, which showed how the open culture of universities like Stanford and firms like HP diffused across Silicon Valley's broader culture, while the more insular corporate culture of Boston's Digital Equipment Corporation made collaboration and knowledge exchange more difficult in that region.

46 Dakhli, M. and D. De Clercq (2004). "Human capital, social capital, and innovation: a multi-country study." Entrepreneurship & Regional Development 16(2): 107-128; Rauch, A., et al. (2013). "National culture and cultural orientations of owners affecting the innovation–growth relationship in five countries."

thrives in cosmopolitan cultures, characterised by openness to global interaction and social tolerance. This increases the ability of actors to respond quickly to changing markets and to innovate by bringing together people with diverse backgrounds.[47] Cultures that are supportive of, and encourage risk taking and collaboration are particularly fertile to entrepreneurship, intrapreneurship, and open innovation. These promote a broader willingness to experiment and take risks, informality of work styles and high occupational mobility that tend to underpin higher levels of new firm formation and innovative activities in general.[48] Innovation culture touches on almost every aspect of our logic map. For instance, it shapes the propensity for actors in the region to seek innovative solutions in research and discovery phases. It affects attitudes of actors involved in the value creation process towards risk and experimentation in implementation and commercialisation. Innovation culture plays a similar role in shaping attitudes and practices in the innovation adoption.

Culture is also relatively difficult to measure and in innovation literature usually relies on surveys where possible and must default to proxies otherwise. Common proxies for innovation culture include indicators of open innovation such as prevalence of strategic partnerships and use of external knowledge; of entrepreneurship such as firm formation rates; and of attitudes towards (entrepreneurial) risk[49]. The UK Innovation Survey collects data on firm knowledge and technology sourcing activities.[50]

Work by Garretsen et al[51] demonstrated not only the importance of entrepreneurial culture on economic growth, but also the relevance of geographically clustered personality traits.

A region's culture permeates almost every facet of the innovation process from propensity to seek partners for research and discovery processes, organisational approaches to the value creation process (particularly commercialisation), and openness to innovation adoption. Innovation culture strongly influences, and is influenced by, *interactions across networks*. It also has reciprocal relationships with enablers such as *sectoral structure* (as different sectors are also sometimes characterised by subcultures), *local institutions* (which often shape regional cultures), *quality of place* (which both enables and is shaped by this factor), *support structures* (which are also vectors of cultural transmission), and the *business base characteristics* (where

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Entrepreneurship & Regional Development 25(9-10): 732-755; Tödtling, F., et al. (2011). "Open Innovation and Regional Culture—Findings from Different Industrial and Regional Settings." European Planning Studies 19(11): 1885-1907.

[47] Saxenian, A. (1994) Regional Advantage: Culture and Competition in Silicon Valley and Route 128 (Cambridge, MA: Harvard University Press); Florida, R. (2000) Competing in the Age of Talent: Quality of Place and the New Economy, Report Prepared for the R.K. Mellon Foundation, Heinz Endowments, and Sustainable Pittsburgh.

[48] Todtling, F. & Trippl, M. (2007) Regional Innovation Cultures, CURE Working Paper. Institute for Regional Development and Environment. Vienna University of Economics and Business.

[49] See https://stats.oecd.org/index.aspx?queryid=70778 for examples at the national scale.

[50] See Jones-Evans, D., et al. (2016). Open Innovation, SMEs and Regional Development: Evidence from the UK. XXVII ISPIM Innovation Conference. Portp, Portugal for open innovation index.

[51] Garretsen H. (2019) *The relevance of personality traits for urban economic growth: making space for psychological factors.* Journal of Economic Geography.

groups of similar firms are both the product of and embody different aspects of regional culture).

Enablers

As with our discussion of the drivers, we will now discuss in more detail each of the primary enabling factors, and provide a definition, some initial thoughts about operationalisation and measurement, and a discussion about the interlinks with drivers and other enablers.

Sectoral structure

A sector is a set of activities which are engaged in producing related product groups for a given or emerging demand and which share some basic knowledge.[52] Sectoral structure refers to the *mix* of sectors and component industries that characterise a regional economy. This mix is a product of past and functions as a constraint on future economic activity. Actors within the economy are in large measure constrained and bounded by the technological and industrial context[53] in which they are located.[54]

This is mostly important to the extent that sectoral mix will have a profound effect on the *knowledge base* of a region. Similarly, to the extent that the activities that firms engage in shape the knowledge space (which can also be described as the technological foundation) of a region, it will also influence degrees of existing and potential *technological relatedness*. Sectoral structure will likely also influence regional innovation culture (as sectors can have their own distinctive subcultures) and be influenced by *innovation culture* to the extent that cultures of openness will affect sectoral growth. Sectoral mix will also influence the potential the emerge of industrial clusters, which rely on the co-location and critical mass of firms in similar or related industries.[55] In other words, in addition to determining degree of relatedness it will also influence potential for specialisation. Industry requirements will determine the required skillset of the labour pool in the area and thus provide the *human capital profile* involved in various aspects of the innovation process. The degree to which heterogeneous firms facing similar industrial contexts can develop common behavioural and organisational traits and develop a similar range of learning patterns, behaviour and organisational forms is also an interesting by-product of the unique sectoral structure of a region.[56] As such, this variable can impact factors such as *business base composition* to the extent that certain industries are dominated by firms of specific sizes (SMEs for instance) or tend to concentrate large multinational enterprises (MNEs). This can also influence export orientation (and reliance on *external connectivity*).

Business base characteristics

The qualities of business base within the economy is a key enabler of innovative activity in the economy. After all, much of the innovation and diffusion process within regions occurs within and between firms. It is decision

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[52] Malerba, F. (2005). "Sectoral systems of innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors." Economics of Innovation and New Technology 14(1-2): 63-82.

[53] Among other factors such as institutions, markets, etc.

[54] NELSON, R. R. (1994). "The Co-evolution of Technology, Industrial Structure, and Supporting Institutions." Industrial and Corporate Change 3(1): 47-63.

[55] Spencer, G. M., et al. (2010). "Do Clusters Make a Difference? Defining and Assessing their Economic Performance." Regional Studies 44(6): 697-715.

[56] Nelson, R. and Winter, S. (1982) An Evolutionary Theory of Economic Change. Harvard, MA: The Belknapp Press of Harvard University Press.

makers within firms that make research and development, innovation adoption, commercialisation, and implementation decisions that impact regional economic performance. Firm structures also influence factors such as *innovation culture* and propensity to be involved in partnerships; do internal research and engage in *knowledge creation* activities; hiring practices (which affect *human capital profiles*), *network engagement*, and location decisions. In short, firm characteristics exert a wide influence across the stages of the innovation and diffusion processes.

While there is no specific magical firm type or mix of firm types, scholarship on firm structures and innovation points a series of characteristics that influence investment, engagement, and intrapreneurship decisions. Factors such as firm size, for instance, influences a variety of investment decisions. Larger firms are more likely to invest in research and development.[57] Firm age affects things such as the propensity for the organisation to undertake risky, and potentially more innovative, knowledge searches[58]; generate innovative output[59], often measured in terms of patents; and adopt innovations[60]. These factors are also affected by firm sector, technological profile, position in the supply chain, and past innovation performance. As such, as with sectoral mix, understanding the mix of businesses and their dominant characteristics can help us understand what patterns of innovation are likely within an economy.

Specifically, business base characteristics shape the *human capital profile* of the region as firm size and age, for example, will typically affect the range of skills demanded. Business base characteristics can also shape the wider regional *innovation culture* to the extent that smaller firms and startups, for example, can be more tolerant of risk, open to collaboration and experimentation.

Strength and engagement of local anchor institutions

Anchor institutions are the large employers large locally embedded institutions, typically non-governmental public sector, cultural, or other civic organisations, that are significantly importance to the economy and wider community life of the places in which they are embedded.[61] Hospitals, universities/colleges, public laboratories, museums, libraries, and sports teams all fall into this category, although innovation literature tends to focus on the first three of these in their capacity as significant knowledge generators. Large firms are also sometimes included in this category, particularly if they have been significant actors in the region for a long time and/or have local origins, although they are sometimes categorised separately as anchor firms.

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[57] Shefer, D. and A. Frenkel (2005). "R&D, firm size and innovation: an empirical analysis." Technovation 25(1): 25-32.

[58] Coad, A., et al. (2016). "Innovation and firm growth: Does firm age play a role?" Research Policy 45(2): 387-400.

[59] Sørensen, J. B., & Stuart, T. E. (2000). Aging, Obsolescence, and Organizational Innovation. *Administrative Science Quarterly*, *45*(1), 81–112. https://doi.org/10.2307/2666980

[60] Balasubramanian, N. and J. Lee (2008). "Firm age and innovation." Industrial and Corporate Change 17(5): 1019-1047.

[61] Goddard, J., et al. (2014). "Universities as anchor institutions in cities in a turbulent funding environment: vulnerable institutions and vulnerable places in England." Cambridge Journal of Regions, Economy and Society 7(2): 307-325.

The term 'anchor' refers to the relative fixity of these entities in contrast to more footloose private firms. Their engagement with and embeddedness within the regional economy stems from their status (usually) as large employers, (often) large owners or tenants of real estate, and (typically) strong historical connection with the place and its economy. These entities generate positive externalities and relationships that can support wider economic activity within the locality.[62] Partly as a product of these interests and partly to support their core missions, these institutions will often deepen their involvement in the local economy whether through civic engagement, strategic partnerships, consulting relationships, public engagement programmes, or collaboratively developing regional knowledge infrastructure.

In addition to being important foundations and engines for the regional economy, anchor institutions are also significant in their capacities to attract firms, talent, and investment to the region. For instance, in science-based industries such as the life sciences, it is increasingly the location of research and development (R&D) related infrastructure such as research-intensive universities and laboratories that encourages the continued clustering of firms in these areas as these organisations with a reputation for excellence function like magnets for firms in related industries.[63]

We measure anchor institutions by counting high-reputation universities based on national rankings. Another way to get at this is to measure the significance of knowledge generating organisations through tracking research funding (e.g. using Innovate UK data). This type of data can also help identify research-intensive anchor firms. Membership in, or leadership of, significant civic organisations and networks is also an important indicator of institutional engagement.

In their capacity as knowledge generators and educators (in the case of higher education) and as international attractors of talent anchor institutions have an important role in shaping both the regional *knowledge base* and *human capital profile* (with sufficiently large degrees of graduate retention). Through this role they can also have an important impact on *innovation cultures* and function as key nodes (and sometimes clusters of nodes) and can stimulate *interaction across networks*. This variable has strong interaction effects across enablers as well. To the extent that anchor institutions can function as multipliers for clustering they can influence *sectoral structure*. As large knowledge generators, they are often home to technology/knowledge transfer entities, incubators, and development programs that function as important regional *support structures*. And as attractors and civically engaged actors anchor entities can contribute positively to *quality of place*.

Quality of place

People, firms, and organisations are attracted to nice places. The late 1990s and 2000s saw the emergence of a considerable body of literature that argued that the broader environment within which economic activity took place could be as powerful an attractor for talent and investment as strong anchor

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[62] Benneworth, P., et al. (2017). "Strategic agency and institutional change: investigating the role of universities in regional innovation systems (RISs)." Regional Studies 51(2): 235-248.

[63] Cooke, P. 2005. Rational drug design, the knowledge value chain and bioscience megacentres. *Cambridge Journal of Economics*, 29(3): 325–341; Gertler, M. S. and T. Vinodrai (2009). "Life Sciences and Regional Innovation: One Path or Many?" European Planning Studies 17(2): 235-261.

institutions and growing clusters.[64] The exact qualities of place that matter, to whom, and at what cost all remain subject to vigorous debate. So, while there is widespread agreement that “place matters” this has resulted in a broad array of qualities of place that might matter. These can be (roughly) categorised as relating to assets/offerings, which are usually qualities of regional physical, cultural, and institutional space, and intangible characteristics related to culture, practice, and modes of operating.

Regional assets/offerings include (but are certainly not limited to!) attractiveness (of urban and living environments); affordability and accessibility of housing and commercial real estate; spatial diversity; richness of cultural and leisure amenities (theatres, art galleries, cinemas, outdoor sports facilities); and presence of (semi) public ‘third places’ for social interaction (for example, bookstores, cafes, parks); transportation networks; alongside the usual package of local public goods[65] (schools, services, etc.).[66] Intangible qualities of place include (and are again not limited to) authenticity, openness to diversity (for example, of ethnicity, sexual orientation, religion); tolerance of alternative lifestyles; presence of a lively (sub) cultural ‘scene’ and street life and ‘buzz’.[67]

Similarly, relevant qualities of place can be viewed through the eyes of firms or of workers. The literature that emerged in 1990s was significant in that it focused on place from the perspective of the individuals and ushered in an era of talent- rather than firm-focused placemaking. This shifted policy making attention to placemaking activities designed to attract and retain talent, particularly catering to knowledge and creative workers. While the value of these programmes remains contested [68] the fact that qualities of place exert an influence on firm and worker location decisions is broadly accepted.

In part due to the breadth and subjectivity of the concept the attractiveness of places can be quite difficult to measure. We operationalise quality of place using indicators in existing quality of life surveys (e.g. Halifax) as well as measures of affordability, and socioeconomic qualities of places.

To the extent that quality of place informs the location decisions of workers and firms it has an important influence on the *human capital profile* and *sectoral structure* of a region. It is also worth noting that both of these variables also shape the characteristics of a place (ie. Places can be attractive due to the existing mix of firms and human capital), so the relationship

[64] See in particular contributions like Florida, R. (2002) The economic geography of talent. Annals of the Association of American Geographers, 92(4), pp. 743–755;. Florida, R. (2002) The Rise of the Creative Class and How It’s Transforming Work, Leisure, Community and Everyday Life. New York: Basic Books; Glaeser, E. L., et al. (2000). Consumer City. Cambridge, MA, Harvard Institute of Economic Research.

[65] See Tiebout, C. M. (1956). "A Pure Theory of Local Expenditures." Journal of Political Economy 64(5): 416-424.

[66] Brown, J. and M. McZyski (2009). "Complexcities: Locational Choices of Creative Knowledge Workers." Built Environment 35(2): 238-252.

[67] Ibid

[68] See contributions like Boom, N. (2017). Rebalancing the creative city after 20 years of debate. In J. Hannigan & R. Greg *The SAGE Handbook of new urban studies* (pp. 357-370). 55 City Road, London: SAGE Publications Ltd doi: 10.4135/9781412912655.n23 and Zukin, S. (2010) *Naked City: The Death and Life of Authentic Urban Places*. Oxford: Oxford University Press.

between all three is reciprocal and reinforcing. To the extent that qualities of place such as density, vibrance, and walkability of employment areas can ease social mixing they can also influence *interaction across networks*. *Innovation culture* is one of the intangible elements of a place that can make it more or less attractive. Because they all shape the broader environment in which innovation takes place in one way or another, all of the enablers impact on quality of place in one way or another. Factors such as *connectivity* affect things such as ease of mobility, traffic congestion, and accessibility. *Support systems*, *business base characteristics*, and *local institutions* are part of the fabric of the region's offering.

Connectivity

So much of the innovation process relies on flows – the flow of goods, services, knowledge, ideas, resources, people. While there are sometimes downsides to extreme openness and mobility on balance reducing the friction involved in these kinds of flows yields positive returns.[69] These flows exist on two different if intersection planes – the tangible (people, things) and intangible (knowledge, experience) – which to varying degrees both rely on physical and digital infrastructure to facilitate and encourage circulation.[70]

Trade relies on the circulation of goods and services. Products need to get to consumers and supply chains need to be connected. The advent of just in time production processes and expectation of overnight delivery means that a large part of competitive advantage now relies on the effectiveness and efficiency of logistics systems, which are themselves dependent on (largely public) infrastructure that connects places.[71] National and regional assets and facilities such as ports, freight rail, airports, and motorway/road networks provide vital links that support industry and is a sector that has itself undergone waves of innovation. The movement of people is equally important. Employees use some of the same networks to commute to work relying on publicly sustained roads, public transportation networks, and airports to get to work and for other business travel. As important as internal circulation is external connectivity, which connects business with other parts of the world and function as the global pipelines of knowledge, investment, and best practice is also critical to enabling innovation.

Intangible flows have increased in importance in the modern economy. Networks as vectors of knowledge circulation between organisations and individuals have always been invisible but now also extend and replicate across very real and physical digital infrastructure.[72] Telecommunications networks and the energy grids that sustain them are essential to innovation. But while these are ubiquitous quality, reliability, and access can be uneven creating crucial barriers to connectivity.

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[69] Bentlage, M., et al. (2013). "Knowledge creation in German agglomerations and accessibility – An approach involving non-physical connectivity." Cities 30: 47-58.

[70] Cooke, P. (2001). "Regional Innovation Systems, Clusters, and the Knowledge Economy." Industrial and Corporate Change 10(4): 945-974; Conventz, S., et al. (2016). Hub Cities in the Knowledge Economy: Seaports, Airports, Brainports. London and New York, Taylor and Francis.

[71] Feder, C. (2018). "Decentralization and spillovers: A new role for transportation infrastructure." Economics of Transportation 13: 36-47.

[72] Rodríguez-Pose, A. and R. Crescenzi (2008). "Research and Development, Spillovers, Innovation Systems, and the Genesis of Regional Growth in Europe." Regional Studies 42(1): 51-67.

We measure regional connectivity in terms of availability and effectiveness of physical and digital infrastructure. These include travel times between locations; proximity and access to airports/roads/rail; and export and import data (as a proxy for global connectivity and reach). Digital connectivity can be measured by extent and access to 4G+ and ultrafast broadband networks.

Connectivity primarily contributes to the *knowledge base* to the extent that connections enable flows of internal and external knowledge. *Interactions across networks* are strongly enabled by extensive and robust digital infrastructure as well as ease of flows of people around regional space. On the enablers side, connectivity is most strongly linked with *quality of place*[73].

Support systems

Innovation in regions is also influenced by the support structures that facilitate knowledge production, value creation, and act as key nodes in networks that facilitate knowledge spillovers. Innovation support systems include resources for business including incubators, accelerators, innovation agencies, tech/science parks, technology transfer infrastructure, industry associations. These organisations and entities typically exist for the specific purpose of supporting local businesses and so are highly active and embedded in the local economy. While support structures can be extraordinarily helpful in increasing business startup and survival rates they are typically regarded as second-generation organisations in the innovation process – they are features associated with mature and innovative regional economies but were not usually the catalysts. They can be, however, integral to sustaining innovation performance over time.

These organisations tend to enable all phases of the innovation process. Incubators, accelerators, and higher education technology transfer organisations focus on facilitating early stages of innovation and particularly on entrepreneurial aspects and other vectors of commercialisation. Technology parks, industry/cluster associations, and innovation agencies provide support to existing firms and tend to count as members firms of various ages from startups to mature anchor firms. These organisations are particularly relevant for their brokerage capabilities.[74] That is, their ability to connect business with the resources (eg financing, expertise), people (eg partners, thought leaders), or information that they need to grow their idea or business.

As such, support systems are critically connected to and are key nodes of *interaction across networks*. To the extent that they bring together regional businesses, support them, and often advocate for them, they are also important repositories and transmitters of *innovation culture*. Finally, because they are typically involved in the knowledge exchange process, they can be core contributors to the development of the region's *knowledge base*. Support systems tend to influence and be influenced by *sectoral structure* and *local institutions* and will have some impact on *business base characteristics*. These will also be core actors in the regional economy and influence *quality of place*.

[73] Across a whole set of dimensions – see, for example, Percoco, M. (2015). "Highways, local economic structure and urban development." Journal of Economic Geography 16(5): 1035-1054.

[74] Ahmad Ali, J. and S. Ingle (2011). "Relationships matter: case study of a university campus incubator." International Journal of Entrepreneurial Behavior & Research 17(6): 626-644.

2.5 Logic Map

The logic map – depicted in Figure 2.5.1 - that emerged from the literature review contains three tiers of elements. The first, the metrics, form the elements of the innovation process and are central to the map. To this point, this project has been principally concerned with understanding the dynamics that affect each of the steps of this process. The second tier is made up of what we've identified as the drivers of these processes – the factors that have the most direct influence on the metrics that we've identified. Finally, the drivers are in turn influenced by a tier of enabling factors.

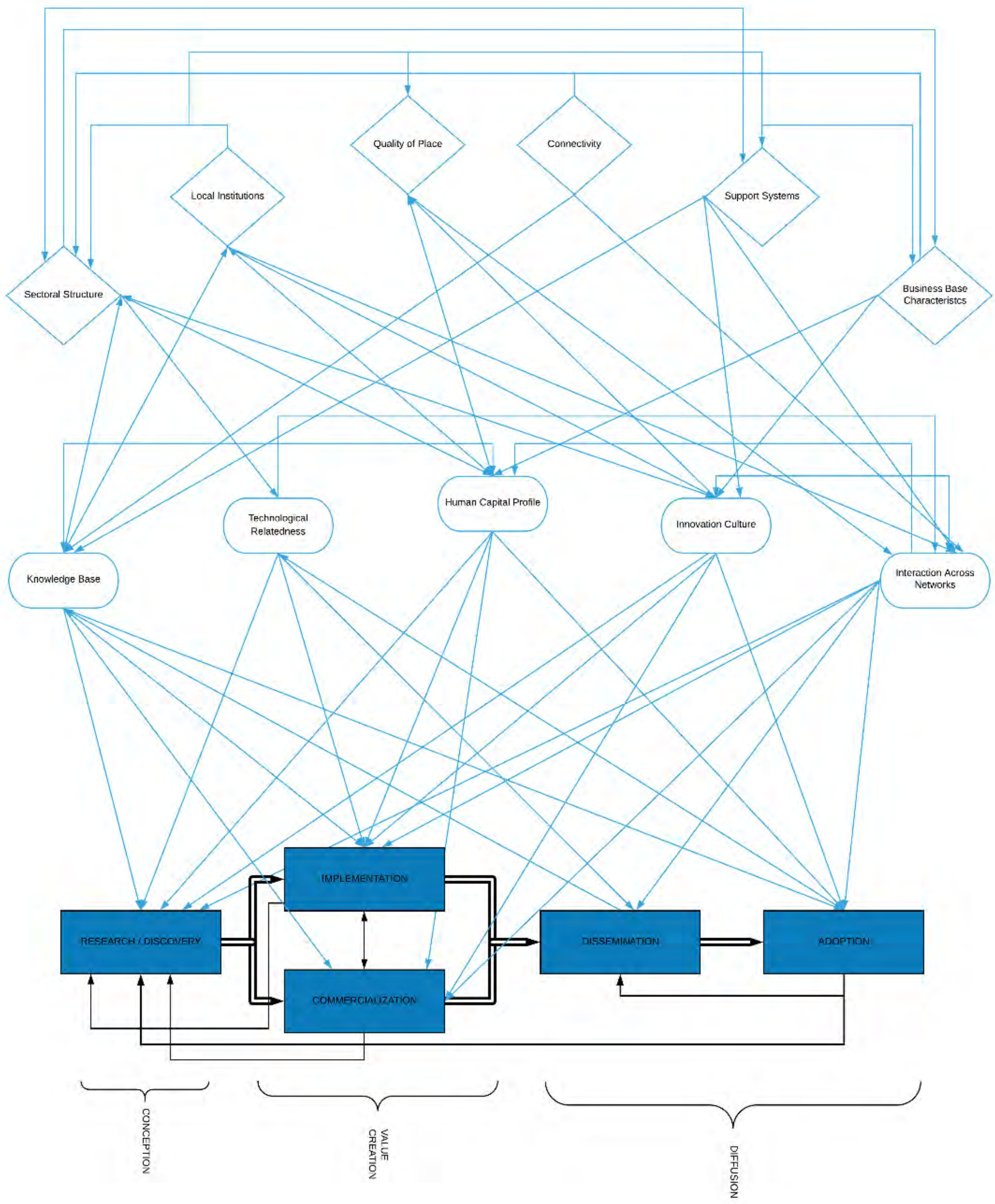
In adopting a systems approach, we explicitly highlight the relationships not only between tiers but also the interactions between elements within each tier. While the map can be difficult to read because of this cacophony of interactions an important contribution of this report is this recognition that drivers do not exist within silos and that groups of factors interact to affect various stages of the innovation process.[75] By analysing data for indicators of each of these variables in light of these relationships and interactions we aim to develop more nuanced insights into the innovation landscape of the North and of potential intervention points.

Table 2.5.1: Matrix of which drivers affect which metrics

Drivers vs. Metrics	Knowledge base	Technological relatedness	Human capital profile	Innovation culture	Interaction across networks
Research /discovery	x	x	x	x	x
Implementation	x	x	x	x	x
Commercialisation	x	x	x	x	x
Dissemination		x			x
Adoption	x	x	x	x	x

[75] We made the deliberate decision to refer to this as a logic map rather than describing it as a map of a system as there are a few elements common to system maps that we cannot (yet) include. For instance, while we can point to interactions and relationships between elements of the map and specify directions of interaction, we don't yet have a sense of magnitude of those interactions between pairs and, consequently, cannot say anything about the significance of these elements relative to one another. As such, this visualisation should be interpreted with caution. While all of the links and drivers and enablers appear to be equal in this depiction, we know that in reality there will be important variations.

Figure 2.5.1: Logic Map showing primary connections between enablers, drivers, and innovation metrics



3 Innovation in the North

3.1 Sources of Data

The table below shows proposed sources of data for each metric, driver and enabler identified in Section 2.2 with explanatory text, caveats and limitations of approach. It is important to note that some variables have reasonably equivalent indicators, whereas others are harder to represent directly, and are instead captured only by proxy. Several indicators could be considered as representing a number of different metrics.

Metrics	Potential Indicators
Discovery	Proportion of firms undertaking R&D Innovate UK data cases
Implementation	R&D Tax Credit claims Firms process innovation
Commercialisation	Total CPC patents Unique CPC patents Firms innovation sales
Dissemination	Firms marketing/strategy innovation
Adoption	Firms introducing new business practices
Drivers	**Potential Indicators**
Knowledge Base	R&D spending
Technological Relatedness	Technological relatedness Technological entropy
Human Capital Profile	Residents qualifications NVQ4+ Skills gaps from new working practices
Innovation Culture	Firms with business plan Firms introducing new methods of work Business birth rate
Interaction Across Networks	Collaboration for innovation Meetup interactions Population 'settled'
Enablers	**Potential Indicators**
Sectoral Structure	Diversity of sectoral specialisation Diversity of R&I intensive sectoral specialisation
Local Institutions	University research base Business, NGO research base Government research base
Quality of Place	Halifax Top 50 ranking Leisure offer
Connectivity	Ultra-fast broadband 4G coverage Access to Economic Mass Airport access
Support Systems	Incubator/accelerators VC investment cases

Business Base Characteristics	High-growth businesses Overseas businesses

3.2 Innovation Process Metrics

We will present and explore the data of the identified metrics of the innovation process at the LEP level across England. This will *not* simply be a ranking or a R-A-G scale by LEP, but a discussion of the range of variation and correlation across the different metrics, and the particular nuances and typicality shown by the 11 Northern LEPs.

Knowledge creation

Research

There is no direct measure of the number of new ideas being created. For a proxy representation for the process of discovery, we have drawn on findings from the UK Innovation Survey, as presented by the Enterprise Research Centre (ERC), that quantifies the proportion of firms reporting to undertake R&D (either internally or externally led).

This particular measure captures firms that are engaging in all stages of stage of the innovation process, and as such it captures both discovery and implementation stages. The firms are captured by this indicator even if only informally or as part of a collaborative effort and regardless of value, and is therefore a much broader measure of R&D than those presented in official datasets (e.g. BERD, GERD etc.)

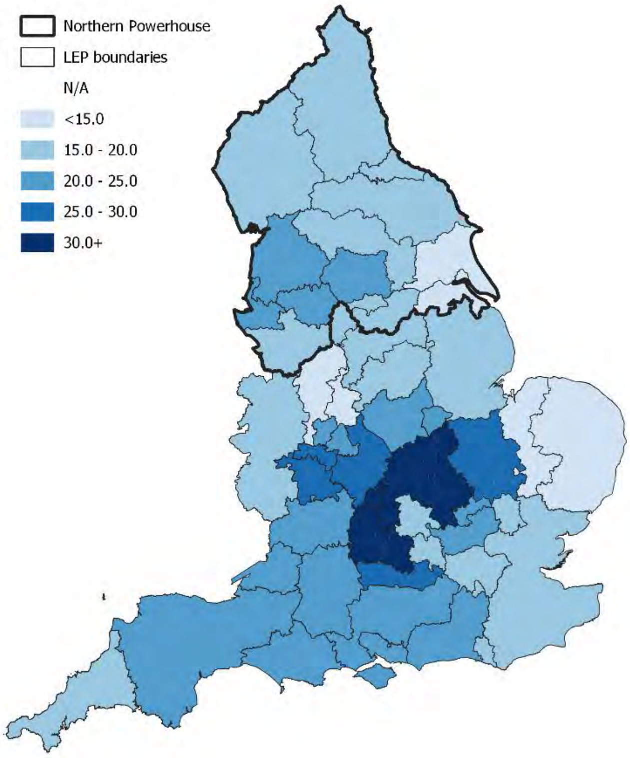
Table 3.2.1: Summary of research indicators

	Average Innovate UK projects awarded, per 10,000 residents	Average value of Innovate UK awarded project, £thousands	Proportion of firms undertaking R&D (%)
Cheshire and Warrington	6.4	93	20.0
Cumbria	3.1	91	16.2
Greater Manchester	4.6	109	22.0
Humber	1.7	89	13.4
Lancashire	3.5	80	22.7
Leeds City Region	5.6	139	21.4
Liverpool City Region	4.6	110	23.2
North East	5.8	306	19.3
Sheffield City Region	7.0	419	19.7
Tees Valley	4.9	1,175	17.0
York, North Yorkshire	1.6	298	17.5
North of England average	4.7	235	19.1
National average	6.2	262	21.2
LEP high	27.2	1,175	40.2
LEP low	1.6	80	13.4

Across England as a whole, the LEPs with the highest proportion of firms undertaking R&D are those located along what the ERC refers to as the ‘arc of innovation’, running through Oxfordshire, the South East Midlands and into

Cambridgeshire. There is also radiation out from this to the South and South West, as well as the manufacturing regions in the southern West Midlands. There are some interesting outliers though; Buckinghamshire and London, two of the strongest performers across the drivers of knowledge creation, have a lower than average proportion of businesses engaged in discovery. This may indicate discovery in these areas – though high value - is highly concentrated in a small number of typically large firms or institutions.

Figure 3.2.1: Proportion of firms undertaking R&D (%)



Source: Enterprise Research Centre (ERC), Cambridge Econometrics (CE)

Within the North, the LEPs with the highest proportion of firms undertaking R&D are typically in more urban geographies: Liverpool and Leeds City regions, and Greater Manchester. However, Lancashire is a positive exception.

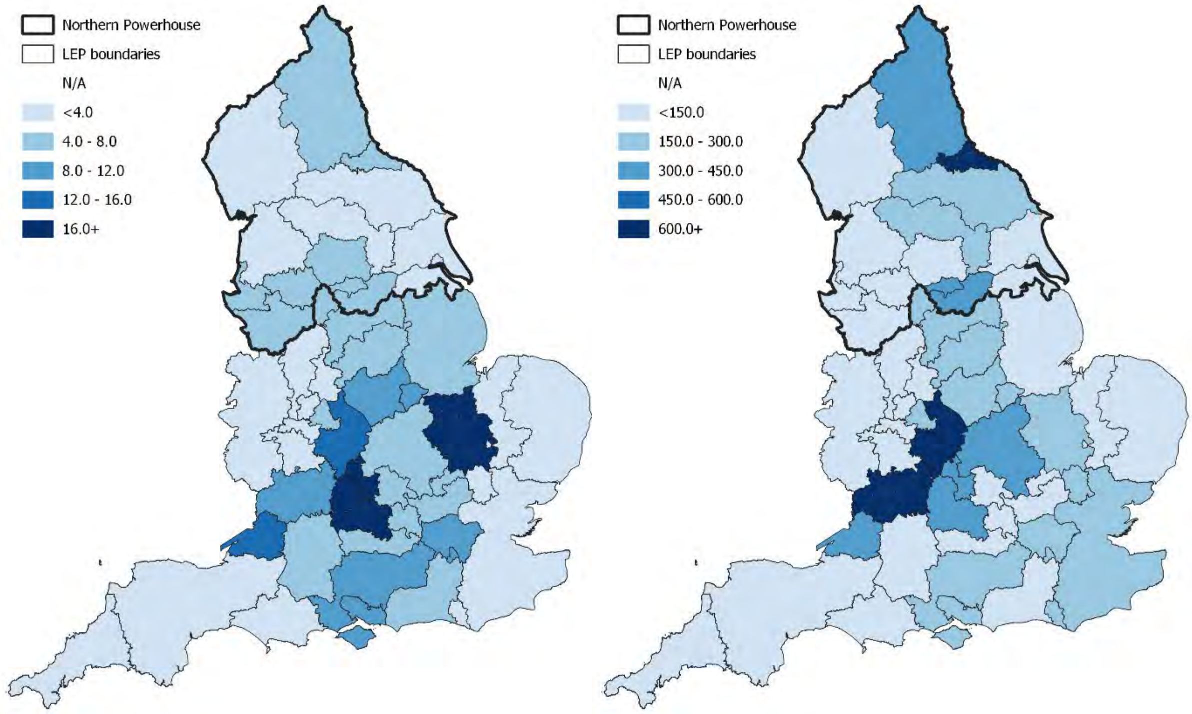
There is a relatively strong correlation between this indicator and the identified underlying drivers of knowledge creation – such as knowledge base and human capital profile – with areas performing well on those factors. However, this is not an exact relationship, with the North's strongest 'discoverers' – Leeds, Manchester, Liverpool and Lancashire – all having lower human capital profiles for instance. This may point towards other, locally specific factors that are independently or collectively driving local discovery. For instance, three of the areas are highly urbanised whilst all have research-driven universities with large accompanying student populations.

Naturally, as a survey-based measure, there will be some margin of error with this indicator, whilst the small sample size might exclude some micro-level discovery. Innovate UK funding data from 2003-2019 shows a slightly different distribution of R&I activity. This funding is distributed through programmes to support innovation-related activities across the country with a particular focus on UK strategic priorities detailed in the Industrial Strategy and elsewhere.

This funding pool supports firms and other research organisations to research and develop a process, product or service; test innovation ideas; and collaborate with other organisations. Consequently, analysing funding patterns provides another way of exploring spatial variations in research and discovery processes.[76]

The data shows about 20% of Innovate UK funded projects (representing 15% of total funding distributed) between 2003-2019 were awarded to consortia with project leads located in the North. While the list of LEPs with the highest number of total projects awarded generally aligns with places with the largest population agglomerations the total value of projects awarded skews towards more heavily towards the northeast of the region (although the larger metropolitan areas round out the top five).

Figure 3.2.2: Average Innovate UK projects awarded, per 10,000 residents (left hand side) and average value of awarded project, £thousands (right hand side)



Source: Innovate UK, CE

When adjusted for population, only a handful of Northern LEPs (including Cheshire and Warrington and Sheffield) were awarded projects at a rate in-line and higher than the national average though. On this measure, the Oxford-Cambridge Knowledge Arc is particularly evident, with both cities leading on project awards. The value of the projects awarded are also typically lower in the North than the national average, though the North East and Tees Valley were notable exceptions to this, with the latter having the highest average value per project awarded in the country (approx. over £1 million).

[76] Note that to the extent that this funding also supports the development process it can also be used as an indicator of value creation.

Value creation

Implementation

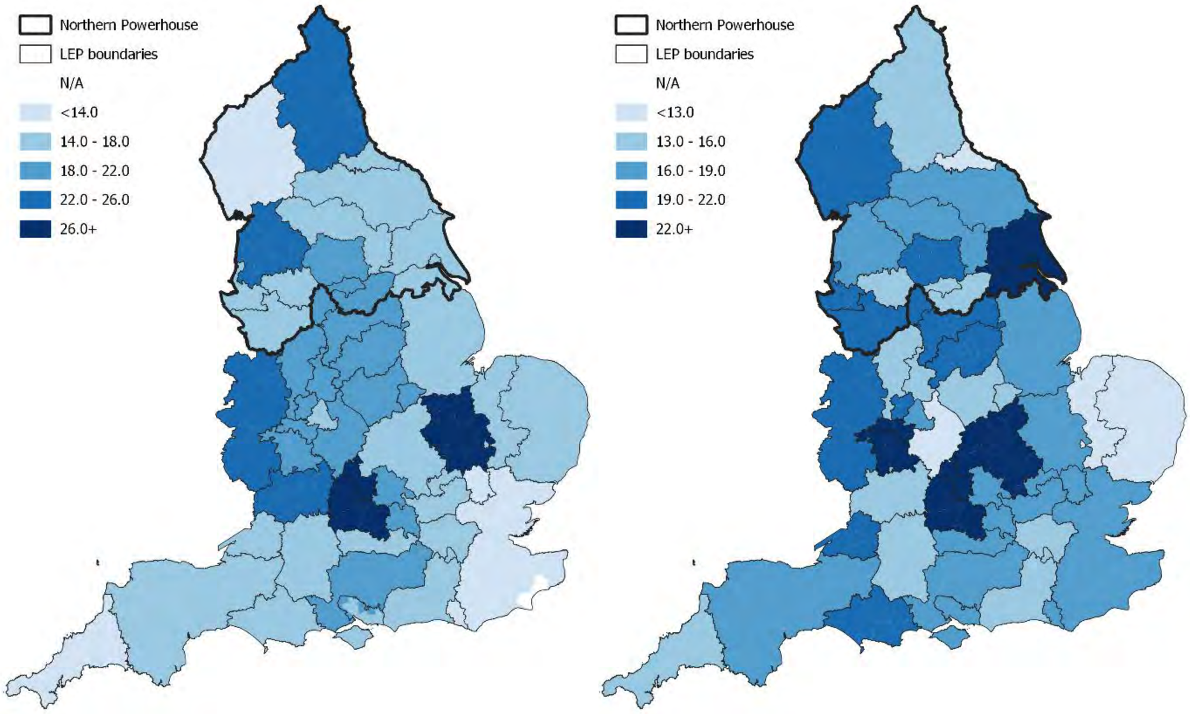
To proxy the implementation of both product and process-led innovations, we have considered two indicators for this stage of value creation; the prevalence of R&D Tax Credit claims within an areas business population, which is typically bias towards the production-side of R&I. For the process-side, again looking at the UK Innovation Survey, we consider the proportion of firms introducing new or significantly improved processes.

Table 3.2.2: Summary of implementation indicators

	Total R&D Tax Credit claims per 1,000 businesses	Proportion of firms undertaking process innovation (%)
Cheshire and Warrington	16.0	19.4
Cumbria	13.3	20.5
Greater Manchester	17.6	16.0
Humber	17.5	23.3
Lancashire	22.1	18.5
Leeds City Region	19.9	19.6
Liverpool City Region	16.2	21.7
North East	25.6	16.0
Sheffield City Region	19.9	15.8
Tees Valley	16.2	12.5
York, North Yorkshire	14.9	18.3
North of England average	18.7	16.6
National average	17.9	16.2
LEP high	34.3	23.8
LEP low	11.2	12.5

There are high levels of product innovation across the North and parts of the Midlands, perhaps reflecting these areas manufacturing strengths; However the Oxford-Cambridge Knowledge Arc is also visible, an area with a lower proportion of manufacturing firms, but high levels of innovation across the board.

Figure 3.2.3: R&D Tax Credit claims (per 1,000 businesses, left hand side) and proportion of firms undertaking process innovation (%, right hand side)



Source: Office for National Statistics (ONS), ERC, CE

Within the North, process innovation is clearly not confined to urban areas, and Humber in particular stands out as an interesting case; the LEP with the lowest proportion of firms undertaking R&D, but the highest proportion of firms undertaking process innovation.

Commercial-isation

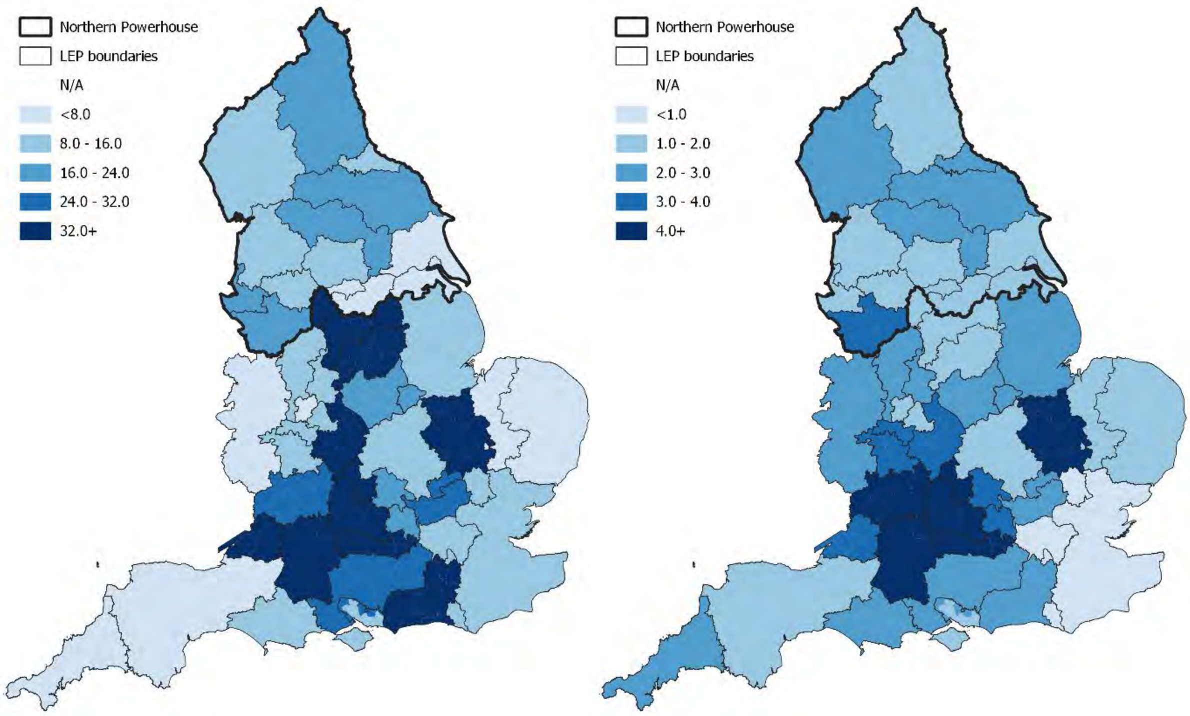
Data on commercialisation is presented below: this uses a mixture of patents data and survey data. The data to investigate invention in English LEP regions overall, and in the 11 LEP regions that are of particular interest in the context of the present study, over the past decades are derived from the EPO PATSTAT database. The patents data are presented on a per capita basis; as such LEP areas with high levels of absolute activity but large populations do not appear highly in the rankings. Most patented inventions are produced in collaboration. Inventor collaborations are usually highly localized, i.e. inventor teams are usually co-located in space while working on the development of a novel product or process. However, even if non-local collaborations are more infrequent, they do serve as an important conduit for accessing extra-local knowledge resulting in knowledge spillovers that might compensate for relevant expertise in the development of an invention that is not available locally.

Table 3.2.3: Summary of commercialisation indicators

	Total CPC patents (per 10,000 adults) 2011-2015	Unique CPC patents (per 10,000 adults) 2011-2015	Proportion of innovating firms' sales attributable to innovation (%)
Cheshire and Warrington	22.0	3.2	27.1
Cumbria	11.4	2.9	18.3
Greater Manchester	10.3	1.3	48.9

Humber	7.3	1.9	33.8
Lancashire	9.8	1.9	36.5
Leeds City Region	10.6	1.5	41.3
Liverpool City Region	16.9	1.3	31.6
North East	17.9	1.6	27.7
Sheffield City Region	7.8	1.8	22.4
Tees Valley	13.2	2.3	41.5
York, North Yorkshire	19.2	3.0	36.4
North of England average	12.9	1.8	32.0
National average	20.2	2.0	35.9
LEP high	111.8	5.5	49.9
LEP low	3.4	0.6	18.3

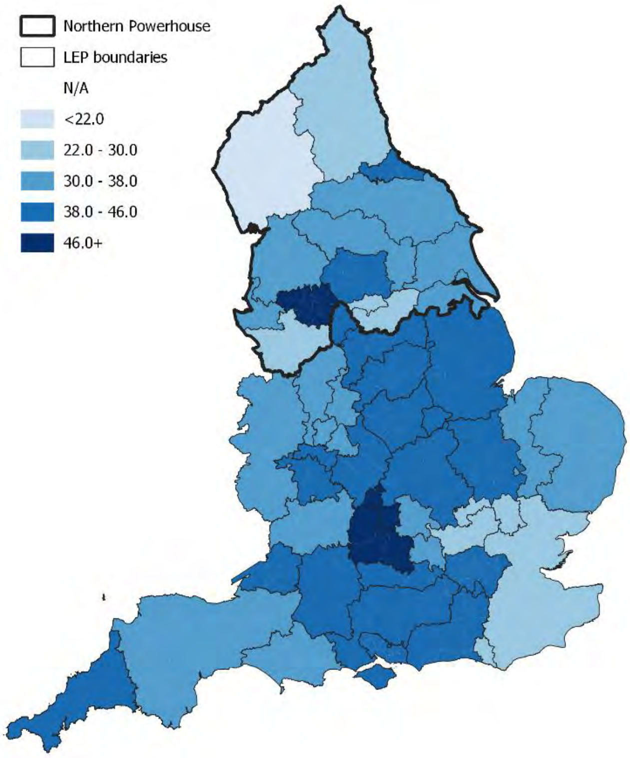
Figure 3.2.4: Total CPC patents (per 10,000 adults, left hand side) and unique CPC patents (per 10,000 adults, right hand side) 2011-2015



Source: European Patent Office, Kogler et al., CE

Patents are allocated to geographies based on fractional inventor counting. Essentially, if a patent was developed by 3 inventors who at the time of invention resided in 3 different countries, only one-third of that patent is allocated to those respective jurisdictions. This is a common way of allocating patenting activity to spatial units. Not surprisingly, LEPs that contain larger metropolitan areas as well as those that are home to some of the leading research-intensive higher education institutions produced comparably more inventions than their other LEP counterparts.

Figure 3.2.5: Proportion of innovating firms' sales attributable to innovation (%)



Source: ERC, CE

Greater Manchester shows up strongly in the measure of innovating firms' sales attributable to innovation, second only to Oxfordshire in this particular measure.

Diffusion

Dissemination

There is no direct measure of the extent to which innovators disseminate their improved products and processes. However, there is one particular method that we can capture, that of commercial marketing. Therefore, to proxy this important stage of the diffusion process we have taken findings once more from the UK Innovation Survey to look at the proportion of firms undertaking marketing and strategy innovation. This particular measure can help identify firms that disseminate innovation through market channels, as such firms will be more likely to deploy larger marketing and advertising budgets, and therefore see greater marketing innovations.

Table 3.2.4: Summary of dissemination indicators

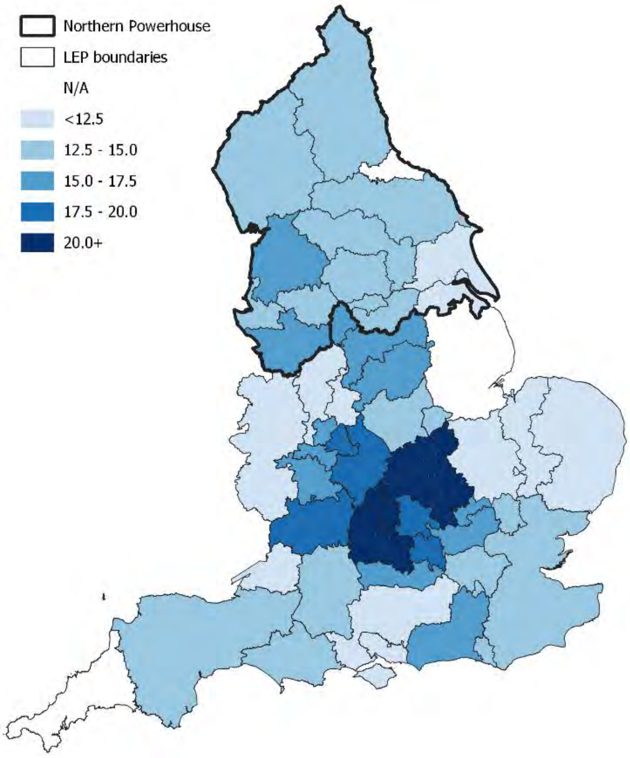
	Proportion of firms undertaking marketing and/or strategy innovation (%)
Cheshire and Warrington	15.5
Cumbria	13.4
Greater Manchester	13.1
Humber	12.1
Lancashire	15.1
Leeds City Region	13.5
Liverpool City Region	14.1
North East	13.0

Sheffield City Region	14.3
Tees Valley	N/A
York, North Yorkshire	12.9
North of England average	13.5
National average	13.8
LEP high	23.4
LEP low	9.3

There isn't a huge amount of variation across the North, with a range of 12.1 to 15.5. The Northern average is in line with the England average of around 13.5%, although below the highest LEP (Oxfordshire), at 23.5%.

There is no real discernible spatial pattern to the proportion of firms undertaking marketing and/or strategy innovation across England as a whole, although central southern England and the south Midlands appear to have high levels in general. Within the North, the highest levels are seen in Sheffield and Liverpool City Regions, Cheshire and Warrington and Lancashire. One question that remains is the extent to which this is driven by sectoral structure.

Figure 3.2.6: Proportion of firms undertaking marketing and/or strategy innovation (%)



Source: ERC, CE

Adoption

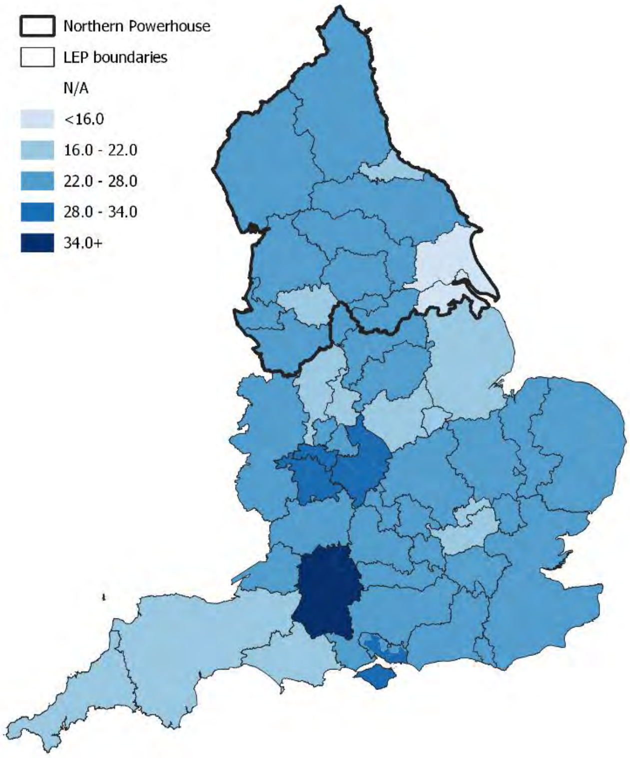
Many products or processes that are adopted by firms or individuals will be done quietly and incrementally, and as such this is a notoriously difficult factor to measure. As with implementation we have sought to compensate for both product and process-led adoption. Unfortunately, a readily-available indicator of product-led adoption has not been forthcoming. For the other measure, drawing once again on the UK Innovation Survey, we consider the proportion of firms that have introduced new business practices to the workplace, which can indicate a firm's absorptive capacity and incidences of process-driven adoption.

Table 3.2.5: Summary of adoption indicators

	Proportion of firms introducing new business practices (%)
Cheshire and Warrington	25.3
Cumbria	23.1
Greater Manchester	20.4
Humber	12.2
Lancashire	24.2
Leeds City Region	24.7
Liverpool City Region	27.0
North East	23.4
Sheffield City Region	25.5
Tees Valley	19.6
York, North Yorkshire	23.5
North of England average	21.8
National average	22.9
LEP high	38.5
LEP low	12.2

Surprisingly, the highest levels of new business practice adoption in England is in Swindon and Wiltshire LEP, followed by Worcestershire LEP and Coventry and Warwickshire LEP. Within the north, the levels are reasonably similar across most LEP areas.

Figure 3.2.7: Proportion of firms introducing new business practices (%)



Source: ERC, CE

3.3 Drivers, Enablers and Barriers

We will then present the data on drivers, enablers and barriers, again, for the purposes of understanding how these manifest at the LEP spatial scale, identifying range of variations and interrelations between different measures, the extent to which these exhibit a spatial element, and the particular position of the 11 Northern LEPs. We also link these back to the logic chain metrics.

Drivers

Knowledge base

Data on R&D spending by categories are shown below.

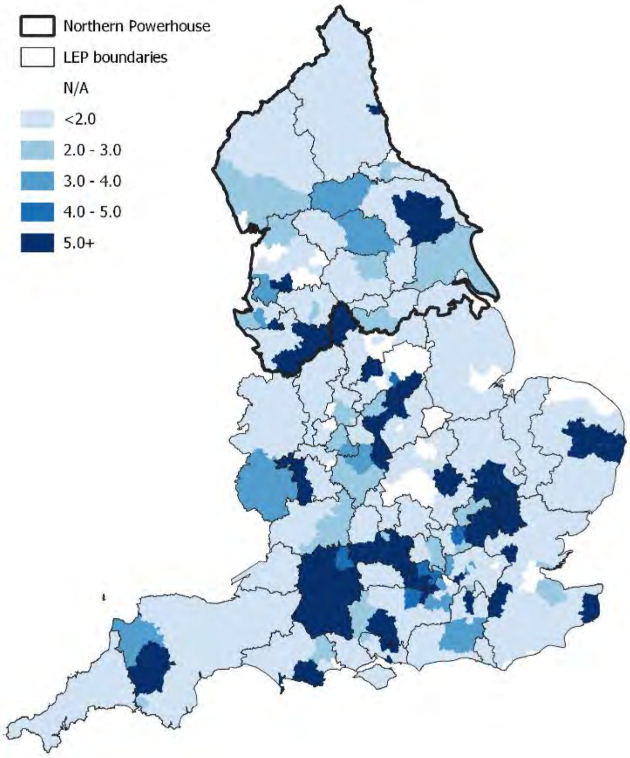
Table 3.3.1: Summary of knowledge base indicators

	R&D spending-output ratio (%)	BERD/Other (GERD and HERD) ratio
Cheshire and Warrington	4.6	12.3
Cumbria	1.5	5.7
Greater Manchester	1.2	0.9
Humber	1.0	10.1
Lancashire	1.3	3.8
Leeds City Region	1.2	1.1
Liverpool City Region	2.6	1.6
North East	1.3	0.9
Sheffield City Region	1.5	0.4
Tees Valley	1.3	0.9
York, North Yorkshire	1.9	1.8

North of England average	1.7	1.9
National average	2.2	2.2
LEP high	12.3	306.7
LEP low	0.4	0.4

Figure 3.3.1 shows the R&D spending-output ratio by LAD. Several authorities around the country have ratios above 4% - but its worth noting that some are considerably higher, at over 10%. Within the North, only Cheshire & Warrington and Liverpool CR above the national average.

Figure 3.3.1: R&D spending-output ratio (%)



Source: ONS, CE

The ratio of R&D spending to GVA correlates closely with the presence of major publicly-financed research institutes. There is also a clear spatial correlation between the location of these institutes and subsequent aggregation of residents with NVQ4+ qualifications over time, as seen below.

Human capital profile

In order to look at the geography of human capital we have taken data from the Annual Population Survey on the qualification levels of working-age residents. By looking at the proportion of residents with NVQ4+, which broadly corresponds to degree-level education and experience, we are able to distinguish areas by their mix of available skills, particularly those favourable to the innovation process.

Table 3.3.2: Summary of human capital profile indicators

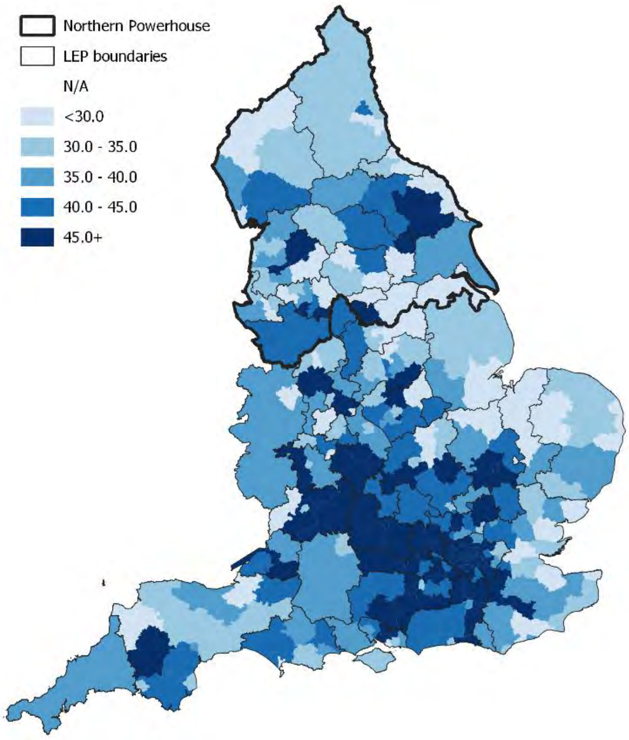
	Proportion of residents with qualifications at NVQ4+ (%)	Proportion of firms with skills gaps attributable to introducing new working practices (%)

Cheshire and Warrington	42.1	20.2
Cumbria	32.5	20.8
Greater Manchester	36.6	20.8
Humber	29.8	32.0
Lancashire	33.8	19.0
Leeds City Region	33.2	27.1
Liverpool City Region	35.0	24.3
North East	32.7	25.2
Sheffield City Region	35.0	24.7
Tees Valley	29.6	33.9
York, North Yorkshire	40.8	26.6
North of England average	34.7	23.6
National average	40.0	22.0
LEP high	54.2	34.0
LEP low	24.7	7.4

The data here shows a clear pattern, with high proportions of NVQ4+ residents in a sweep across central, southern England, from Bristol in the west to Cambridge in the East, and from the south coast up to the south Midlands. It is worth noting that this is not an area with a particularly concentrated number of universities; a significant proportion of these residents have mostly relocated here at some point after graduation.

There are notable pools of skilled human capital the North: Cheshire and southern Manchester, Sheffield, central Lancashire, Leeds and York and their immediate rural hinterlands in North Yorkshire. Such pooling is often shaped by either the quality of the local skills ecosystem (e.g. North Yorkshire), a net inflow of skilled migrants from elsewhere (e.g. Manchester), and in some cases a combination of both (e.g. Cheshire). As a whole though, the North’s human capital profile is significantly lower, especially between the Humber and Leeds, around the Tees Valley and parts of Lancashire.

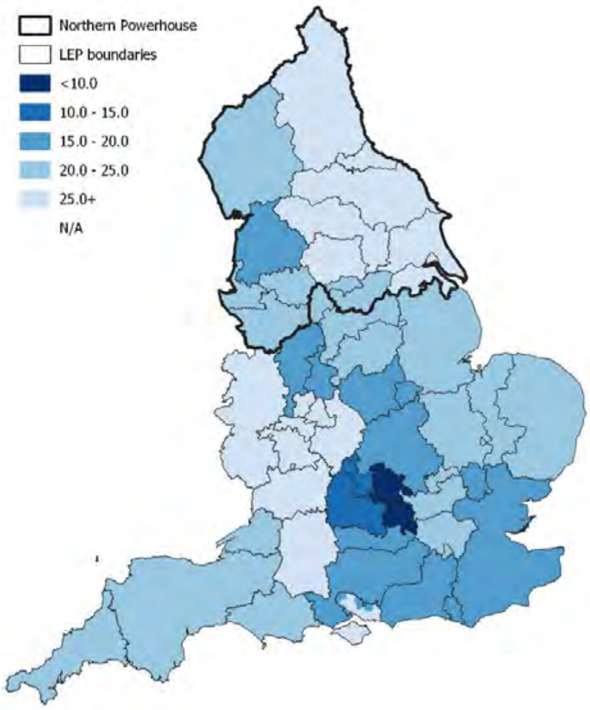
Figure 3.3.3: Proportion of working-age residents with NVQ4+ qualifications (%)



Source: ONS, CE

Beyond looking at qualification-based measures of human capital, we have also sought to assess the flexibility and absorptive capacity of human capital in the face of technological and process-led innovations in the workplace. Specifically, we have drawn on findings from the Employer Skills Survey (ESS) on skills gaps attributable to employers introducing workplace innovations.

Figure 3.3.2: Proportion of firms with skills gaps attributable to introducing new methods of work (%)



Source: Employer Skills Survey (ESS), CE

The data broadly shows a subtly different picture to the overall human capital profile. Firms in the North West appear to have less difficulty in accessing the skills they need following the introduction of new working practices than elsewhere in the North.

Technological entropy and relatedness

Technological relatedness refers to the degree to which the products of a region are similar to one another – draw on similar knowledge bases, make use of similar production processes or routines, use similar technologies, or rely on similar inputs. Places characterised by the production of a diversity of related technologies are said to exhibit related variety, which tends to encourage industrial cross-fertilisation and knowledge spillovers. The knowledge space methodology features a variety of measures that all provide different insights into the degree, sources, and characteristics of technological relatedness. We highlight two here: entropy and relatedness

Entropy measures the degree of diversity of technological classes within a region. These can be conceptualised as the number of building blocks available from which new combinations of ideas can be generated. Relatedness complements the measure of entropy by highlighting how closely connected the diversity of technologies is.[77] This is a rough proxy for the likelihood and relative frequency that we might expect the building blocks will be combined in novel ways as the economy develops. This might be conceptualised as the potential (innovation) energy of a region.

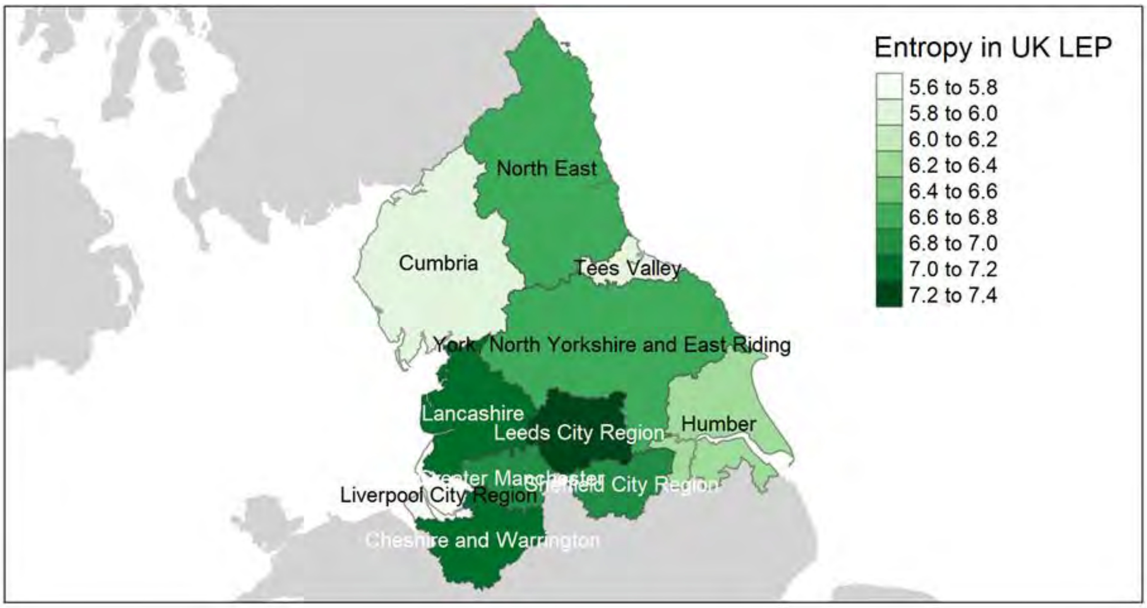
Table 3.3.3 shows entropy scores for the NP11 LEPs. It shows that while most NP11 LEPs fall somewhere in the middle of the ranking, Northern LEPs are also among the most technologically diverse (Leeds City Region) and the least technologically diverse (Liverpool City Region) across the three study time periods displayed. This demonstrates that LEPs in the North have some of the economies in the country with the largest amounts of raw material for recombinant innovation and some of the least. Entropy in the North is also shown in Figure 3.3.4.

Table 3.3.3: Entropy and technological relatedness scores for NP11 LEPs

	Technological Entropy	Technological Relatedness
Cheshire and Warrington	7.02	3.26
Cumbria	5.98	2.34
Greater Manchester	6.91	3.33
Humber	6.2	2.48
Lancashire	7.14	3.28
Leeds City Region	7.24	3.37
Liverpool City Region	5.66	2.34
North East	6.77	2.84
Sheffield City Region	6.97	3.09
Tees Valley	5.92	2.57
York, North Yorkshire	6.66	2.99

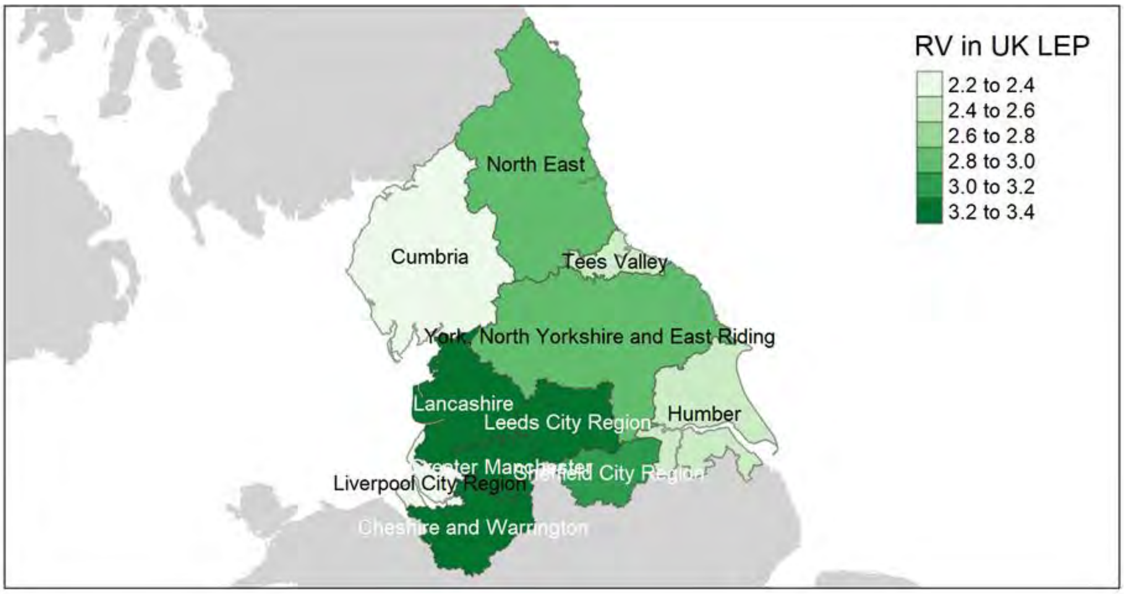
[77] The calculation of these measures is presented in more detail in Appendix B.

Figure 3.3.4: Technological Entropy in the North of England



Shown in Figure 3.3.5 are the average technological relatedness scores for NP11 LEPs. In these study time periods, all NP11 LEPs fall outside of the top five and tend to cluster in the middle of the rankings (although Leeds City Region makes an appearance in 9th place in the 1996-2000 period). While average relatedness score doesn't directly translate into economic success, previous research has shown a correlation between higher scores and patenting rates.

Figure 3.3.5: Technological Relatedness in the North of England



Taken together an interesting pattern emerges. First, while many parts of the region have promising levels of industrial diversity they don't tend to be in technologies or industries that are closely related suggesting that these regions may not be able to effectively capitalise on their diverse technological profiles. Secondly, while rankings have indeed shifted over time on both measures the places that lead and lag tend to be fairly stable.

Levels of interaction across networks

As emphasised earlier, approximating networks and their interactions can be a difficult and time-consuming process, particularly to a detailed and representative spatial level. For this factor, we initially draw once more on the UK Innovation Survey to look at the proportion of innovation -active firms that report collaborating for innovation – an indicator of pre-existing networks and interactions.

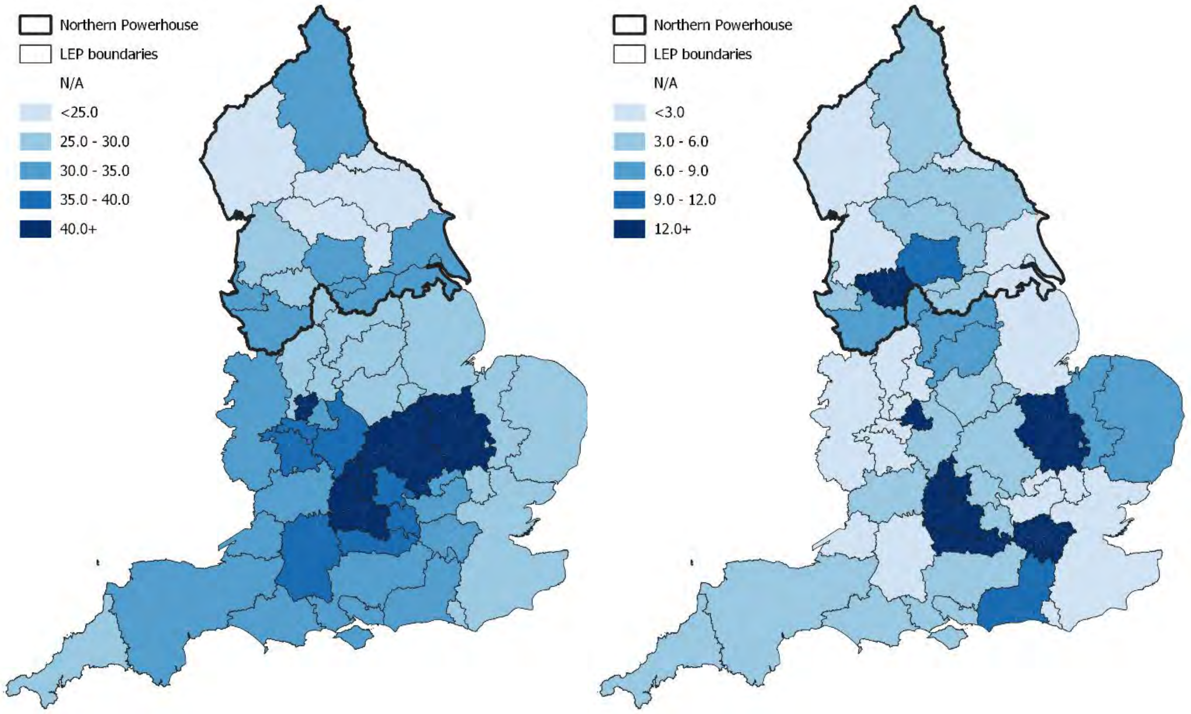
Table 3.3.4: Summary of levels of interaction across networks indicators

	Proportion of innovation-active firms collaborating for innovation (%)	Science and tech-based 'Meetup' interactions (per 1,000 adults)	Proportion of population 'settled' (not moved over previous 12-months, %)
Cheshire and Warrington	33.5	6.4	90.7
Cumbria	22.1	0.2	91.1
Greater Manchester	27.4	29.4	89.7
Humber	34.4	1.9	89.9
Lancashire	29.4	0.7	90.5
Leeds City Region	34.0	10.3	89.7
Liverpool City Region	31.5	4.3	91.2
North East	31.1	4.9	90.9
Sheffield City Region	30.9	4.5	90.6
Tees Valley	21.1	1.0	90.7
York, North Yorkshire	23.8	3.2	88.7
North of England average	28.6	9.1	90.3
National average	31.7	31.6	89.0
LEP high	48.1	162.5	91.5
LEP low	21.1	0.1	85.2

We also present novel data on Meetup interactions; Meetup is an online membership service used to organise formal and informal groups and events, and is especially popular within the tech and scientific communities. Utilising TechNation data that specifically segmented such users, the incidence of these interactions should reflect areas that have a higher probability of facilitating both formal and informal knowledge networks and spill overs.

Finally, we include data on the percentage of the residential population that has lived in the LEP for longer than 12 months. This isn't a direct measure of interaction across networks; however, it is a useful proxy: inward migrants are not only likely to bring in external knowledge, and continue to interact with networks external to the LEP geography.

Figure 3.3.6: Proportion of innovation-active firms collaborating for innovation (%, left hand side) and science and tech-based 'Meetup' interactions (per 1,000 adults, right hand side)



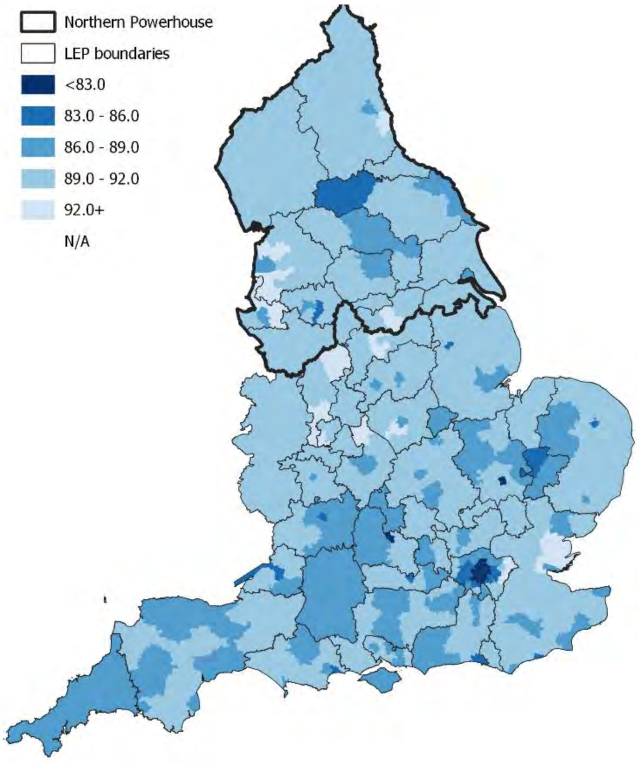
Source: Meetup, TechNation, CE

There is a clear correlation between an area's innovation performance and their likelihood of collaborating. The 'arc of innovation' is again particularly evident, with just under half of innovators in Oxfordshire collaborating with an external partner, almost double the average for the North. Stronger collaboration is also evident in the West Midlands, around Birmingham in particular. The East Midlands meanwhile is a notably less frequent innovation collaborator, as are the more rural extremities of the East and South West.

Innovators are generally much less likely to collaborate in the North, particularly across its more rural innovation networks, such as Cumbria and North Yorkshire. Tees Valley meanwhile has the lowest collaboration rate in the country. Performance is stronger around the North's university towns and cities, such as Liverpool, Leeds, Sheffield, Newcastle, Durham and Hull. Manchester is a notable exception however, with one of the lowest collaboration rates out of all city regions.

The geography of Meetup interactions is – unsurprisingly - dominated by London, but there are also clear and established networks around the Cambridge, Oxford and Thames Valley innovation hubs, whilst Birmingham has a notable presence in the Midlands. In the North, Manchester facilitates the greatest number of such interactions, reflecting its vibrant tech community, with the 4th highest number of interactions in the country. Leeds and Cheshire also feature highly, but away from this corner of the North West, the level of interactions start to drop off significantly, particularly in rural and coastal communities.

Figure 3.3.7: Proportion of population 'settled' (not moved over previous 12-months, %)



Source: Meetup, TechNation, CE

As a final proxy for interactions, we also look at the proportion of an area's population that has moved over the past 12 months (excluding students). Areas that have a lower 'settled' population could have an increased likelihood of interactions with external networks, particularly international, as labour and associated knowledge interacts and spillovers. The data shows that there is a slight correlation between less-'settled' populations and research and innovation activity – Oxford and Cambridge for instance are notable hotspots outside of London. Away from parts of North Yorkshire (which could be skewed by military flows), residents in the North are generally more 'settled', and potentially, as a result, less likely to interact with external networks.

Innovation culture

For this factor, it is important to note we are not looking to identify the practice of innovation, but rather the collection of attitudes, outlooks, norms, and beliefs that can help inform the practice of innovation. We have therefore drawn on a variety of data that can help illustrate attitudes and characteristics that are conducive to innovation. This includes the proportion of firm's business planning (from the ESS), the proportion introducing new methods of work (from the ERC), as well as broader measures of entrepreneurial activity and business dynamism (start-up rates, from ONS Business Demography).

Table 3.3.5: Summary of innovation culture indicators

	Proportion of firms with a business plan (%)	Proportion of firms introducing new methods of work (%)	Business birth rate (per 1,000 adults)
Cheshire and Warrington	60.4	20.4	6.5
Cumbria	52.1	13.6	4.2
Greater Manchester	60.2	19.4	9.6

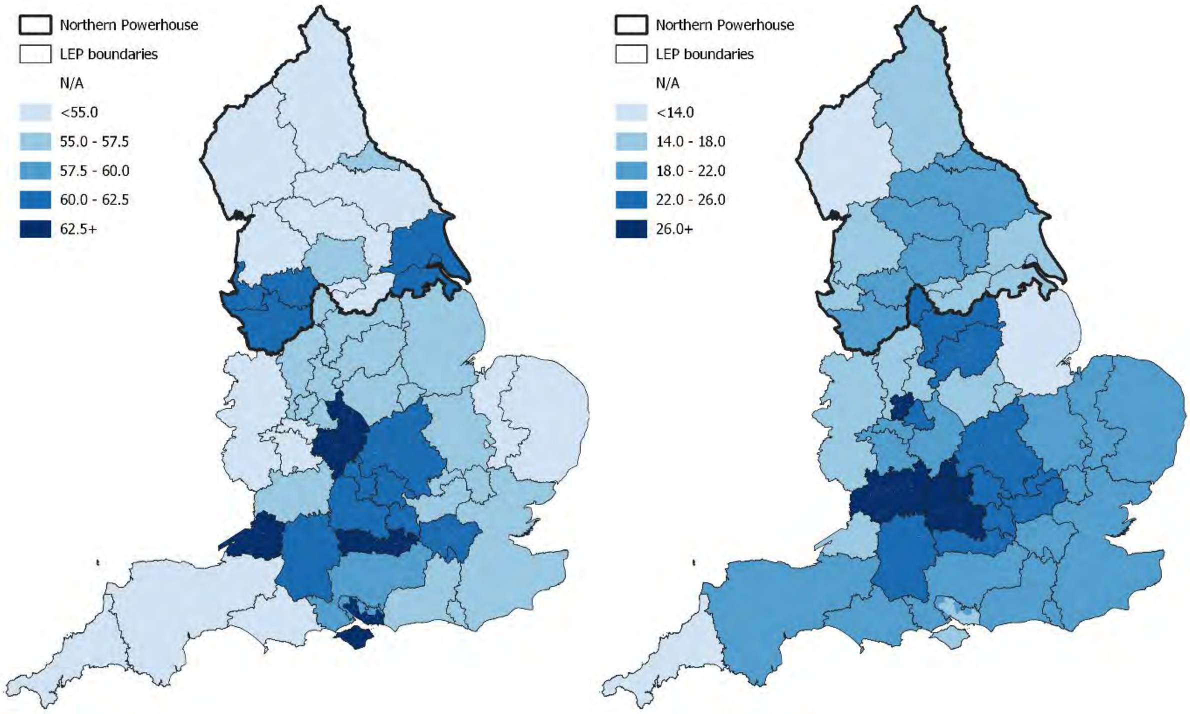
Humber	60.6	16.7	4.7
Lancashire	54.5	17.8	5.4
Leeds City Region	55.6	21.1	5.8
Liverpool City Region	62.0	16.2	6.5
North East	52.7	15.1	4.1
Sheffield City Region	51.7	17.7	5.0
Tees Valley	55.7	19.4	5.0
York, North Yorkshire	52.9	19.0	5.1
North of England average	55.1	17.7	6.1
National average	56.6	19.9	7.5
LEP high	66.8	28.5	13.8
LEP low	50.5	12.5	4.1

Source: ESS, ERC, ONS, CE

There is some indication that existing businesses characteristics and attitudes can reflect potential innovation performance. Businesses along the ‘arc of innovation’ for instance are much more likely to have a business plan or to have introduced new methods of work than elsewhere in the country. Moving away from this central ‘arc’, the likelihood decreases, with the probabilities much lower in more rural, periphery areas such as Cornwall, East Anglia and along the Welsh border.

Within the North, businesses are more likely to display such characteristics in the urbanised parts of the North West, notably Liverpool, Manchester and Cheshire. In more rural parts of the region, such as the North East and Cumbria, this likelihood decreases. The performance is largely mixed elsewhere, with Leeds and Humber for instance close to if not exceeding the national average. Notably, Sheffield is second to only Cornwall for having the lowest proportion of businesses with a business plan.

Figure 3.3.8: Proportion of businesses with a business plan (%, left hand side) and proportion of firms introducing new methods of work (%, right hand side)

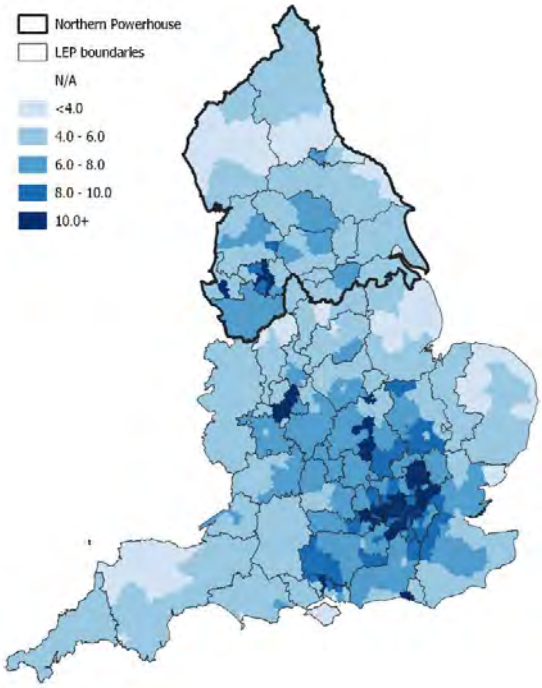


Source: ESS, ERC, ONS, CE

A similar pattern emerges when looking at indicators of entrepreneurial activity. The business birth rate (i.e. start-up rate) in particular shows a close correlation once more with the central ‘arc’, particularly for corridors coming out of London (e.g. along the Thames Valley, M11/Stansted corridor, M3 corridor). The West Midlands also has notable pockets of entrepreneurial activity focused around Birmingham, but away from London and this central ‘arc’, low levels of enterprise become evident, especially in periphery rural and coastal areas.

Within the North, Manchester and Liverpool remain the entrepreneurial hotbeds of the region, with performance cooling off considerably away from this corner. As with the South, entrepreneurial activity is significantly lower in the periphery rural and costal parts of the region. The relationship between enterprise and innovation performance seems to weaken in the North, and appears to be more reflective of (particularly service-based) agglomeration.

Figure 3.3.9: Business birth rate (per 1,000 residents)



Source: ONS, CE

Enablers

Sectoral structure

In order to assess the level and characteristics of sectoral specialisation at the LEP geography level, we accessed 2018 BRES employment data at the 5-digit level. We then recombined some sectors with low overall UK employment totals in order to create a comparable dataset.

Using this data, we were able to calculate location quotients for approximately 400 sub-sectors for each LEP. These were then categorised into 12 sectoral groups based on inter-sectoral network analysis, based on the following two factors:

- Skill relatedness, to study which industries use similar workforce. Data assembled by Neffke et al. (2017) is used to capture skill relatedness across industries. This analysis builds on the work of Froy (2019), who uses the same data to study industry relatedness in the greater Manchester area. Neffke et al. (2017) measures labour flows from one industry to another to assess whether different sectors use workforce with similar skill set and technologies. Although, their analysis refers to German labour flows, Froy (2019) argues that the same skill relatedness measure could be applied to the UK too, as it is driven by the production technology. Following this argument and in absence of similar data set for the UK, this analysis also builds on German labour flows. Based on the data set of Neffke et al. (2017), an industry-industry skill relatedness matrix is used here to learn which sectors use similar workforce to each other. Hiring from a similar pool of workers could be a strong determinant for firms in different sectors to operate at the same location.
- Input-Output relationships, to study supply chain links across industries. Based on the ONS intermediate consumption table for the

UK (2016), this analysis built a matrix to capture supply chain relationships across industries. If firms within one sector use the intermediate product of another, it could drive those firms to move closer to each other and minimize transport costs.

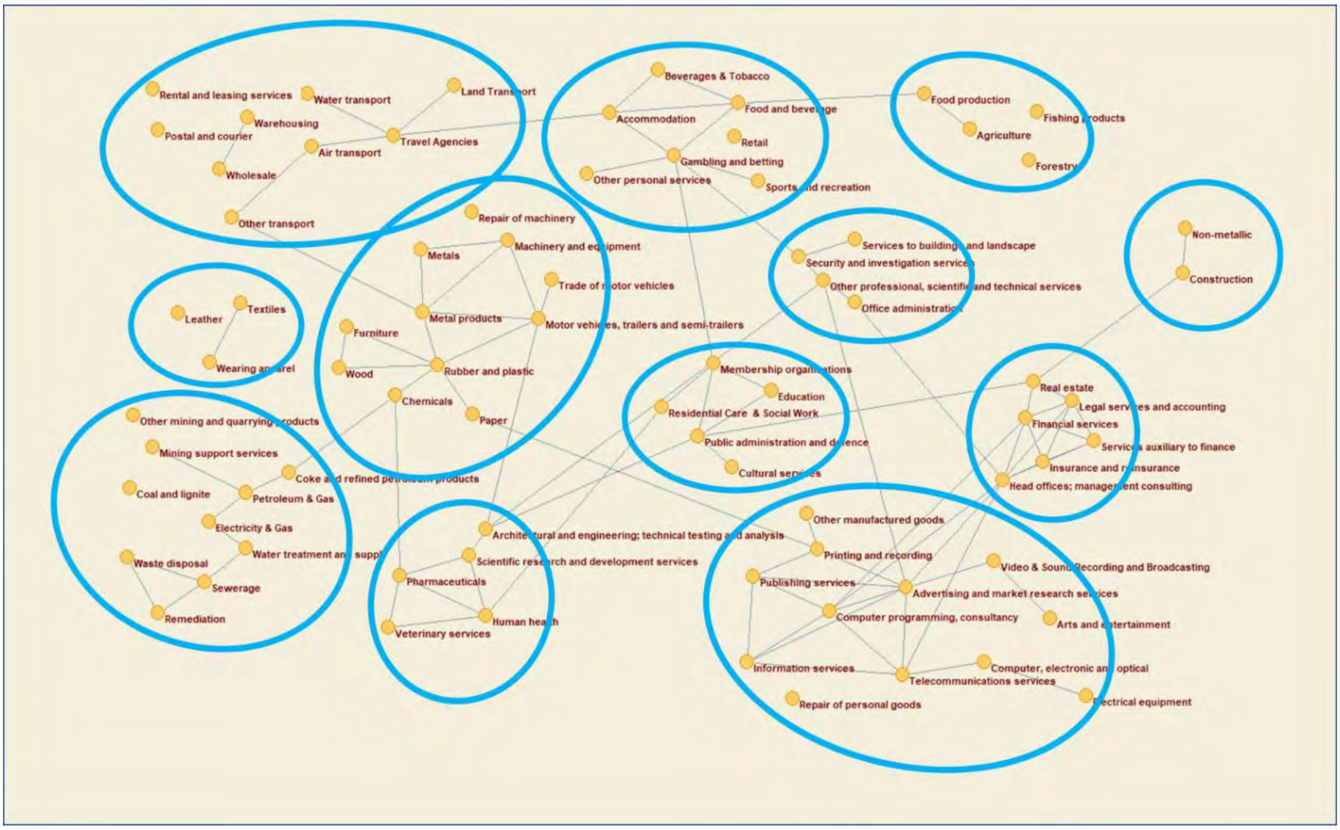
To model how these drivers could form industry groups, we applied a network-science-based analysis. The 400 sub-sectors were matched to the 78 industry sectors used by Neffke et al. (2017), and adjacency matrices were created which reflect the links across sectors. To follow the simplest possible method, we considered an undirected and unweighted network of the sectors. This means that the direction of labour flows and the direction of input-output links across sectors were not considered. The average strength of directed links captures well enough their importance. To keep the analysis as simple as possible, an unweighted network was created for both type of relationships. This means that instead of adding weights to industry-industry connections we focused on the information whether they are connected or not. Using these restrictions, three binary and symmetrical adjacency matrices were created to form networks. The first two creates networks based on skill-relatedness and IO relationship across industries. Combining their information, a third matrix is formed as a sum of the two other matrices. Linkages are formed based on an edge cut-off value of 0.35 – this was chosen to allow distinct groups to be identified.

The following 12 groups were identified (initialisation in brackets):

- Agri-Food (AF)
- Business Support Services (BS)
- Construction Co)
- Consumer Services (CS)
- Extraction & Utilities (EU)
- Finance, Law & Management (FL)
- Manufacturing & Industry (MI)
- Media & Technology (MT)
- Public Services, Education & Social Welfare (PE)
- Science & Healthcare (SH)
- Textiles & Clothing (TC)
- Transport & Logistics (TL)

To qualify as a sub-sectoral specialisation, the LEP geography must have a location quotient of greater than 1.5 in that sub-sector.

Figure 3.3.10: Network relationships between sub-sectors, author's groupings



Source: CE calculations based on data from ONS, Neffke et al.

The number of sub-sectoral specialisation in each sectoral group is shown below for each LEP area.

Table 3.3.6: Sub-sectoral specialisations (See list on page above for abbreviations)

	AF	BS	Co	CS	EU	FL	MI	MT	PE	SH	TC	TL
Cheshire and Warrington	2	2	5	11	5	5	4	8	2	7	1	10
Cumbria	6	0	8	21	2	1	7	1	6	4	0	11
Greater Manchester	0	7	4	13	1	11	3	5	2	0	4	9
Humber	7	4	5	5	6	0	9	1	3	1	1	9
Lancashire	6	3	6	18	4	1	8	3	5	0	4	11
Leeds City Region	2	4	2	2	7	5	3	5	4	0	3	5
Liverpool City Region	1	4	2	9	3	4	3	1	5	6	0	9
North East	2	3	10	7	5	1	5	7	6	2	0	9
Sheffield City Region	2	3	9	4	4	3	9	4	7	0	0	4
Tees Valley	0	1	8	7	8	3	2	1	5	2	0	8
York & North Yorkshire	7	1	4	12	3	3	2	3	12	3	0	12
England Average	4.0	2.8	4.1	7.9	4.1	4.3	4.7	6.6	5.4	2.8	0.9	10.3
England Max	12	7	11	21	8	25	10	29	14	7	6	23

Analysis of the table above reveals a number of patterns; firstly, not all sectoral groupings contain the same number of sub-sectors; some are relatively ubiquitous, others less so. Specialising in 6 different *Textiles and Clothing* sub-sectors is a more significant indicator of a diverse and comprehensive level of specialisation in that industry, than specialising in 6 different transport and logistics sub-sectors, for example.

Within the North, patterns of groups of specialised sectors can be identified.

- Cumbria, Humber, Lancashire and York & North Yorkshire have the highest number of specialisations in different Agri-food sub-sectors.
- Greater Manchester have the highest number of specialisations in different Business Services sub-sectors.
- Cumbria and the North East LEP have the highest number of specialisations in different Construction sub-sectors.
- Cumbria and Lancashire have the highest number of specialisations in different Consumer Service sub-sectors.
- Humber, Leeds City Region and Tees Valley have the highest number of specialisations in different Extraction and Utilities sub-sectors.
- Greater Manchester has the highest number of specialisations in different Finance, Law and Management sub-sectors.
- Humber, Lancashire and Sheffield City Region have the highest number of specialisations in different Manufacturing and Industry sub-sectors.
- Cheshire and Warrington, Greater Manchester, Leeds City region and North East LEP have the highest number of specialisations in different Media and Technology sub-sectors.
- York and North Yorkshire has the highest number of specialisations in different Public Services, Education & Social Welfare sub-sectors.
- Cheshire & Warrington and Liverpool City Region have the highest number of specialisations in different Science and Healthcare sub-sectors.
- Greater Manchester and Lancashire have the highest number of specialisations in Textiles and Clothing, sub-sectors.
- Cheshire & Warrington, Cumbria, Lancashire, and York & North Yorkshire have the highest number of specialisations in different Transport and Logistics sub-sectors.

The results were combined into a composite indicator: the diversity of sectoral specialisation is calculated as the weighted sum of all specialised sub-sectors and is effectively a measure of the total number of individual niches an area is specialised in, weighted by disubiquity.[78]

[78] The disubiquity of a sector is an inverse measure of the number of LEPs with a location quotient greater than unity in that sector.

Table 3.3.7: Summary of sectoral structure indicators

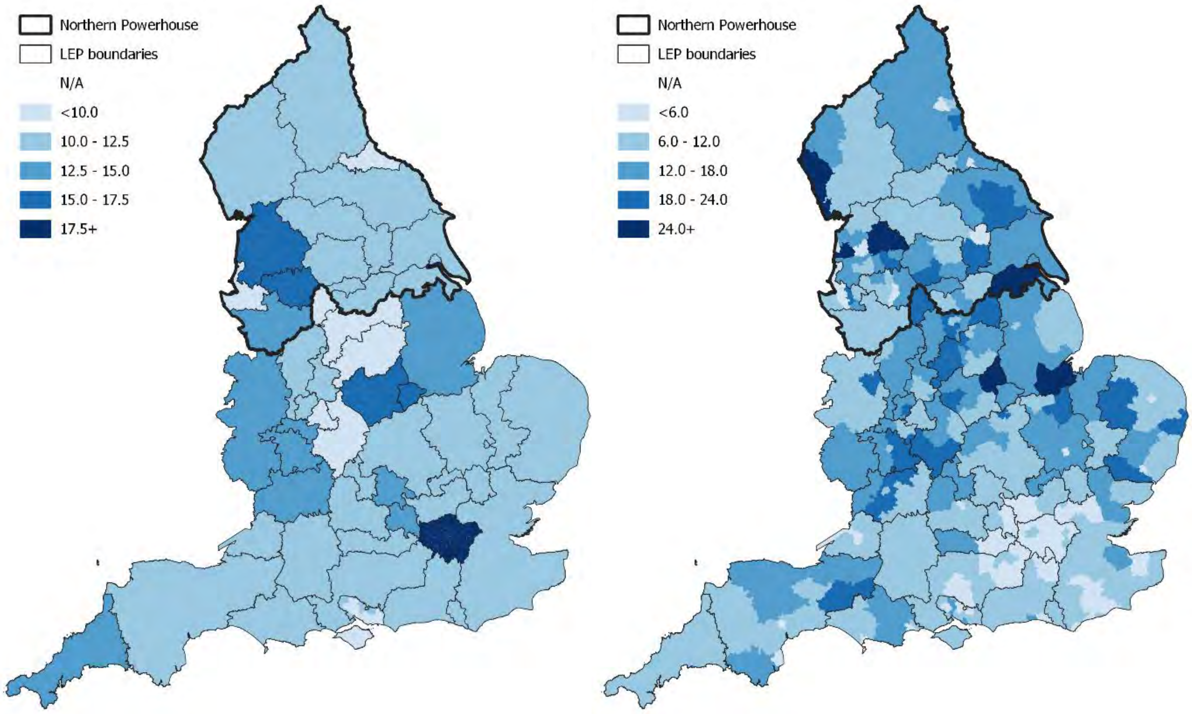
	Diversity of sectoral specialisation	Manufacturing and production employment share, %
Cheshire and Warrington	13.3	9.6
Cumbria	12.1	17.5
Greater Manchester	15.2	9.4
Humber	11.5	18.7
Lancashire	16.2	14.9
Leeds City Region	11.6	12.4
Liverpool City Region	9.7	8.6
North East	11.1	12.8
Sheffield City Region	10.1	12.2
Tees Valley	8.8	11.3
York, North Yorkshire	11.4	10.5
North of England average	11.7	11.9
National average	11.8	9.2
LEP high	20.1	18.7
LEP low	8.8	2.8

Source: ONS, CE

London is the highest placed LEP in terms of the diversity of its sectoral specialisation. Within the North, Greater Manchester and Lancashire show the highest level of diversified specialisation across all sectors, whereas Cheshire and Warrington has the highest level of diversity in R&I intensive sub-sectors.

Given the role manufacturing and production-based industries have in R&I and its composition, particularly in the North, consideration is also given to the intensity of such industries in local economies. Humber has the highest share of economic activity attributable to manufacturing and production in the country, whilst Cumbria and Lancashire also feature highly. Besides Liverpool, all Northern LEP areas have shares above the national average.

Figure 3.3.11: Overall sectoral specialised diversity (left hand side) and manufacturing and production employment share, % (right hand side)



Source: ONS, CE

Business Base Characteristics

As emphasised earlier, there is no specific firm type or mix of firm types that can drive innovation, and indeed there is a large and complex array of characteristics and variables that could be considered. Here, we have specified a small number of business base characteristics that literature shows can influence investment, engagement, and entrepreneurship decisions. Specifically, we look at the incidence of high-growth businesses and overseas businesses within local business populations.

Table 3.3.8: Summary of business base characteristics indicators

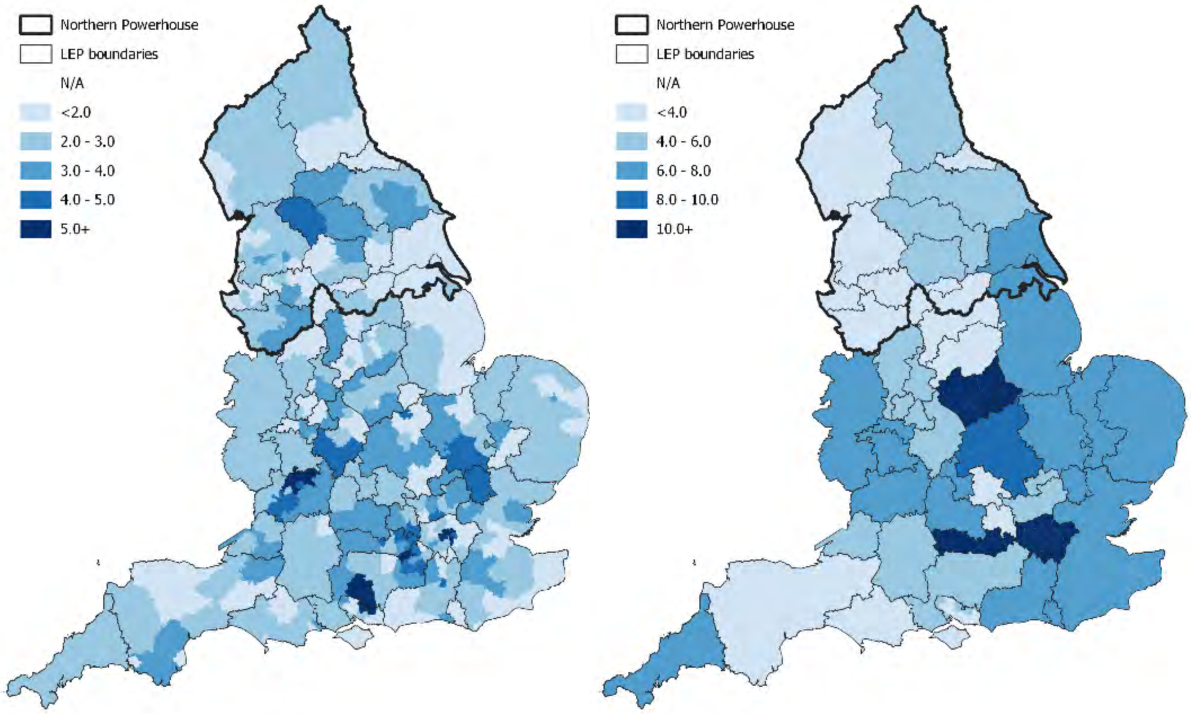
	High-growth businesses (per 10,000 adults)	Proportion of businesses with HQ overseas (%)
Cheshire and Warrington	3.2	3.2
Cumbria	1.9	2.7
Greater Manchester	2.7	3.8
Humber	1.9	6.1
Lancashire	2.5	2.7
Leeds City Region	2.6	4.9
Liverpool City Region	1.8	3.1
North East	2.0	4.3
Sheffield City Region	1.9	3.8
Tees Valley	1.6	3.0
York, North Yorkshire	2.8	4.1
North of England average	2.3	4.2
National average	2.7	6.5

LEP high	4.0	18.9
LEP low	1.6	1.8

Though inner London dominates the high-growth picture, there is notable radiation out, to the north into Cambridgeshire, and the west through the Thames Valley and M3 corridor. Coverage remains robust throughout the ‘arc of innovation’, though parts of the West Midlands and the West of England show stronger representations.

The North is largely underrepresented in terms of high growth firms, especially around its urban centres; Manchester, Leeds, Sheffield, Liverpool and Hull all have lower shares than elsewhere in the country. Concentrations actually appear greater in rural parts of the region, such as Cumbria, North Yorkshire and Northumberland, though as a proportion, the actual values in these areas may be low.

Figure 3.3.12: The proportion of high growth businesses (per 10,000 adults, left) and the proportion of businesses with HQ overseas (right, %)



Source: ONS, ESS, CE

The incidence of overseas businesses (specifically those with their HQ’s overseas) also appears to influence spatial patterns of research and innovation activity; greater concentrations are evident in and around London, and along the ‘arc of innovation’. Proximity to major airports appears a factor, with the highest representations appearing near Heathrow, or in the proximity of Birmingham or East Midlands airports. Despite the strength of Manchester airport, representation is significantly lower throughout large parts of the North, with only the Humber showing levels of overseas activity in line with the national average, a possible reflection of its internationally-facing energy and low-carbon sector.

Strength and engagement of local anchor institutions

As with interactions across networks, measuring the engagement of local anchor institutions can be a complex and time-consuming process. However, data relating to the strength and incidence of local anchor institutions are more readily available, and are taken as a proxy here. Specifically, we consider the presence of research staff within higher education, the private and third sector, and central government, as a proportion of the local population. The higher incidence of research staff should reflect the strength/reputability, and likely engagement capability of said institutions

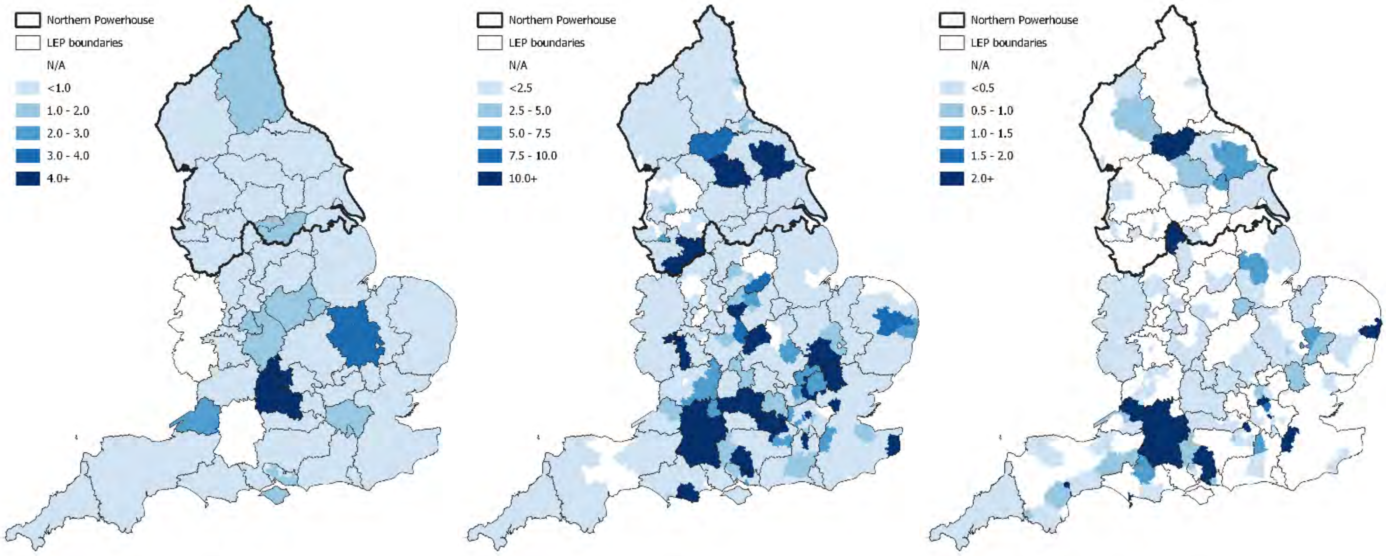
Table 3.3.9: Summary of strength and engagement of local anchor institutions indicators

	University research staff (per 1,000 adults)	Business and NGO research staff (per 1,000 adults)	Central government research staff (per 1,000 adults)
Cheshire and Warrington	0.2	6.4	0.0
Cumbria	0.1	0.2	0.1
Greater Manchester	1.0	0.5	0.1
Humber	0.5	0.3	0.0
Lancashire	0.8	0.6	0.1
Leeds City Region	0.9	0.6	0.0
Liverpool City Region	0.9	1.5	0.1
North East	1.3	0.8	0.0
Sheffield City Region	1.1	0.6	0.1
Tees Valley	0.2	2.0	0.0
York, North Yorkshire	1.0	4.3	0.7
North of England average	0.9	1.3	0.1
National average	0.9	2.8	0.3
LEP high	4.8	25.9	3.4
LEP low	0.0	0.0	0.0

Unsurprisingly, two areas dominate the university research landscape, driven by their world-leading, research-driven universities: Oxford and Cambridge, who account for almost half of all universities research capacity. Though university research activity is evident throughout the country, few have such high concentrations. The West of England, with its cluster of universities in Bath and Bristol, comes close, whilst concentrations are also evident in parts of the Midlands (Leicestershire and Warwickshire) and the south coast.

In the North, university research activity is most clearly concentrated around Sheffield and in the North East, both of which have Top-50 ranking universities under the Research Excellence Framework. York and Manchester also have concentrations of research activity above the national average, whilst Leeds, Lancashire and Liverpool, again all with high-ranking universities, also perform strongly. Cheshire, Cumbria, Humber and Tees Valley in contrast have relatively limited university research profiles, unsurprising given their comparatively lower university presence.

Figure 3.3.13:- University research staff (per 1,000 adults, left hand side), business and NGO research staff (per 1,000 adults, middle) and central government research staff (per 1,000 adults, right hand side)



Source: Research Excellence Framework, ONS, Annual Civil Service Employment Survey, CE

In terms of business and NGO innovation, activity becomes more spatially diverse. Though pockets along the 'arc of innovation' and the M4 corridor are most obvious, concentrations are also evident at locations of significant private sector sites, often in otherwise rural areas such as Winchester, Malvern, Wiltshire and Bournemouth. In the North, the greatest concentrations are in Cheshire and York & North Yorkshire, two notable research ecosystems, the former businesses-driven, the latter university and NGO.

And when looking at central government research activity, the spatial pattern is much more concentrated. Notably, there is limited direct central government activity along the arc of innovation. Pockets of activity reflect the location – sometimes geographically driven - of central government research hubs, such as GCHQ in Gloucestershire, the MOD and Dstl in Wiltshire, CEFAS on the east coast and the MOD in North Yorkshire. In fact, in the North, central government research activity is largely military-affiliated, with only a limited non-military presence.

Quality of place

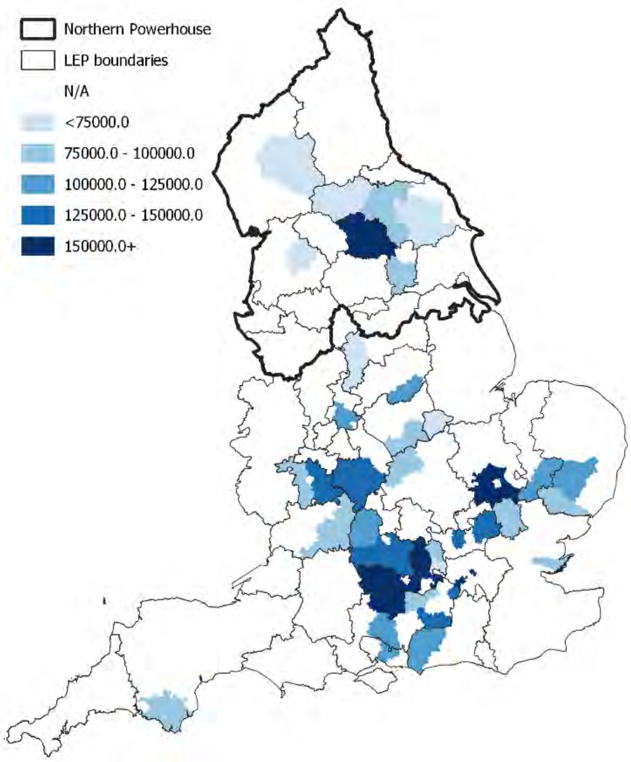
To help articulate quality of place in a timely and concise manner, we draw on a readily available, popular and widely recognised measure of quality of place, the Halifax Quality of Life Survey. The Survey, which has been reported for almost two decades, considers a diverse range of local areas indicators such as residents' health and life expectancy, wellbeing, earnings, employment, crime rates and weather to rank areas in the UK for their desirability and liveability.

Table 3.3.10: Summary of quality of place indicators

	Proportion of residents residing in Halifax Quality of Life Survey Top 50 places (%)	Arts, culture and leisure offer (employment per sq. km)
Cheshire and Warrington	0.0	16.9
Cumbria	10.6	2.8

Greater Manchester	0.0	77.5
Humber	0.0	8.2
Lancashire	4.0	15.5
Leeds City Region	0.0	38.5
Liverpool City Region	0.0	72.3
North East	0.0	7.8
Sheffield City Region	0.0	29.4
Tees Valley	0.0	22.7
York, North Yorkshire	54.5	5.2
North of England average	3.6	13.9
National average	9.6	16.3
LEP high	63.1	299.1
LEP low	0.0	2.8

Figure 3.3.14: Halifax Quality of Life Survey Top 50 places, and accompanying population



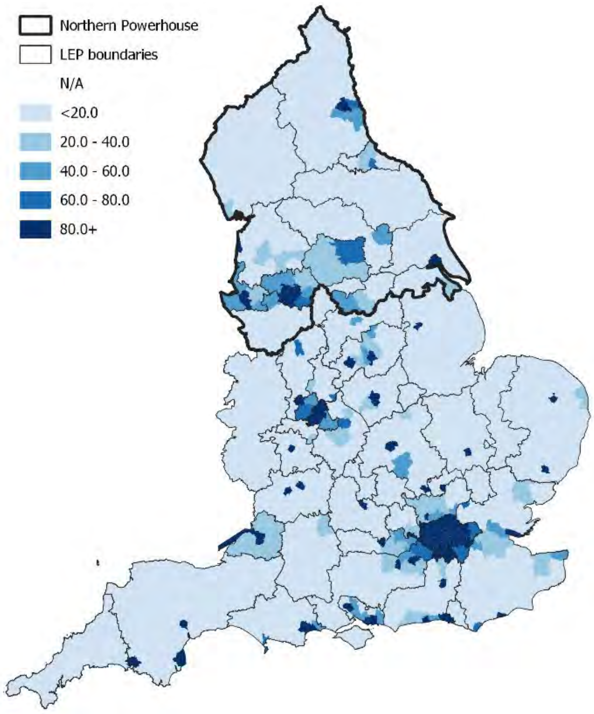
Source: Halifax, CE

As reported by Halifax there is a notable North-South divide in the rankings, but of more interest is how this manifests itself in the research and innovation environment. In the South, the greatest quality of place is largely evident in and around areas with existing research and innovation ecosystems, such as along the Thames Valley, around Oxford and Cambridge, and down the M3 Corridor. Though the actual research centres in these ecosystems (i.e. the urbanised research environment e.g, Oxford City) may not rank highly, their surrounding hinterland, often rural/semi-rural, typically does. The ongoing ability of these areas to consistently attract and retain mobile workers is perhaps partly explained by these statistics.

Within the North, this relationship is less exact. North Yorkshire dominates performance in the region, with over half of its residents residing in Top 50 areas. But away from York and the governments research presence in North Yorkshire, there is a limited research and innovation landscape – especially business-driven - in this part of the region, although its possible that residents of this area could also commute into Leeds City Region. Likewise, most of the areas performing well on the Survey in the north are highly rural, with populations less than 80,000 (in contrast to those in the South, which tend to be more densely populated), with Harrogate and its hinterland the only exception.

Another attractor is the quality and level of at an area's arts, culture and leisure offer. We proxied this here by employment density to capture the level of cultural and entertainment offer. Unsurprisingly, urban areas show up strongly, demonstrating their undoubted and growing attractiveness to young workers. London is the artistic, cultural and leisure focal point of the South, though there is a strong surrounding network in regional urban centres. Liverpool, Manchester and Leeds strong a form offer in the North, though away from these areas only Newcastle and Hull are other notable clusters of activity.

Figure 3.3.15: Arts, culture and leisure offer (employment per sq. km)



Source: ONS, CE

Connectivity

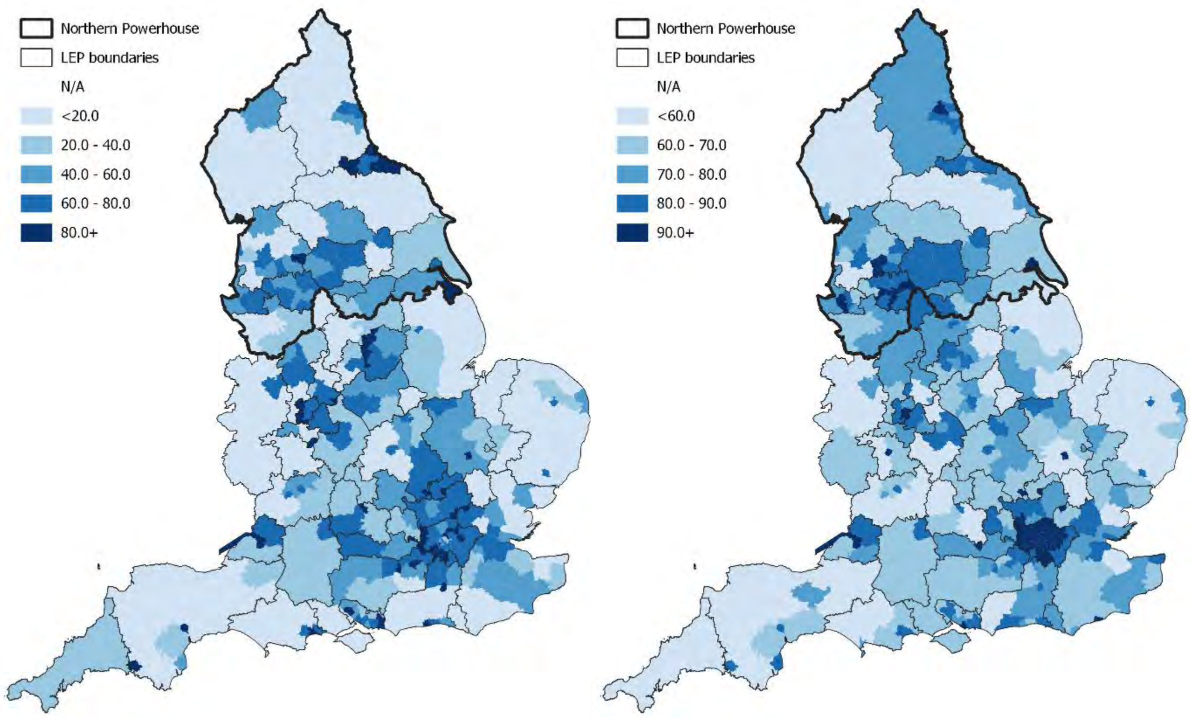
We initially draw on the two strands of connectivity, physical and digital. For physical connectivity, we use Access to Economic Mass (ATEM) to quantify the impact of regional and national connectivity, and access to airports to quantify international connectivity. For digital connectivity, we consider the availability of ultrafast broadband, as well as the availability of 4G within business premises.

Table 3.3.11: Summary of connectivity indicators

	Proportion of premises with ultra-fast broadband (%)	Proportion of premises with indoor 4G coverage (%0	Access to Economic Mass (ATEM) score	Access to airport score
Cheshire and Warrington	31.9	72.6	280.3	0.2
Cumbria	11.6	56.3	49.2	0.0
Greater Manchester	61.5	84.9	226.0	0.3
Humber	59.5	73.4	168.0	0.0
Lancashire	49.1	77.8	120.3	0.0
Leeds City Region	59.3	85.5	190.8	0.1
Liverpool City Region	58.0	79.7	301.2	0.2
North East	36.0	80.1	275.0	0.1
Sheffield City Region	43.8	79.2	218.1	0.0
Tees Valley	84.3	78.9	138.2	0.0
York, North Yorkshire	30.0	69.0	77.0	0.0
North of England average	50.2	79.0	175.3	0.1
National average	51.5	78.1	210.8	0.2
LEP high	84.3	95.9	544.5	0.6
LEP low	11.6	56.3	41.9	0.0

In terms of digital connectivity, there is an unsurprising bias towards urbanised areas, but there are some interesting patterns. Generally, there is a notable lack of digital connectivity in rural areas, but we notice that rural areas close to London and along the ‘arc of innovation’ – broadly, the home counties - have notably better digital infrastructure than more periphery rural and coastal areas (such as the East, South West and Welsh borders). Of course, it is hard to identify whether this is a “cause or effect”, as it may be the existing economic success of these areas has enabled such improvements.

Figure 3.3.16: Proportion of premises with ultra-fast broadband (% left hand side) and proportion of premises with indoor 4G coverage (%, right hand side)



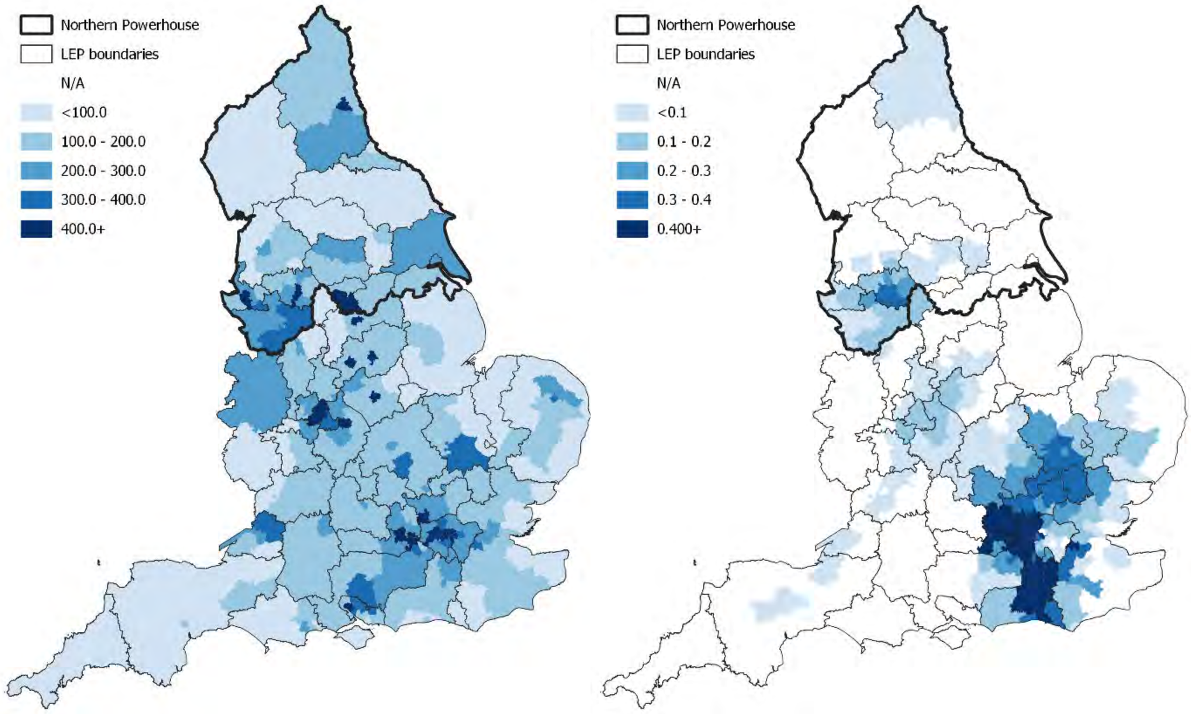
Source: Ofcom, CE

In the North, Liverpool, Manchester, Leeds and Sheffield all stand out for having well supported digital infrastructure, though Cheshire, rather surprisingly given its economic profile, is a pocket of poor connectivity. Rural parts of the North display generally lower levels of digital connectivity, though parts of the Humber and Tees Valley stand out as interesting outliers, with some of the strongest digital connectivity in the country.

In terms of regional and national physical connectivity (proxied by ATEM), the spatial pattern in the South is dominated by proximity to London and Birmingham. This is unsurprising given the established transport infrastructure threaded through and between such areas. The South West, East Midlands and East all stand out as having lower levels of physical connectivity, reflecting their more peripheral nature.

In the North, access to economic mass in concentrated across the line of cities stretching from Liverpool to Hull. Rural parts of the region, notably Cumbria and North Yorkshire, display lower levels of physical connectivity than equivalent rural areas in the central southern part of the country, and are more comparable to the peripheral areas of the South West or Lincolnshire.

Figure 3.3.17: Access to Economic Mass (ATEM) score (left hand side) and access to airport score (right hand side)



Source: CE, Department for Transport, Steer, Prof Bernie Fingleton

International connectivity, quantified by the proximity to airports (accounting also for capacity), shows a strong Southern bias, though even this is restricted to a confined corner around London (particularly areas close to Heathrow and Gatwick). The northern half of the 'innovation arc' is well serviced by proximity to both Heathrow and Stansted. Manchester is the focal point of international connectivity in the North, though this accessibility soon levels off moving away from the city. There are also pockets of international connectivity around Leeds and Newcastle.

Support systems

For looking at local support systems, we draw on Nesta's novel directory of incubators and accelerators across the UK. Though incubators and accelerators are often only a part of the support ecosystem, such sites also capture (through co-operation and events) the presence of wider support networks, such as banks, business chamber, sector bodies, LEPs, and local authorities. To supplement this, we also look at TechNations findings on venture capital (VC) investment cases within local business populations, to specifically consider the spatial pattern of the equity finance support system.

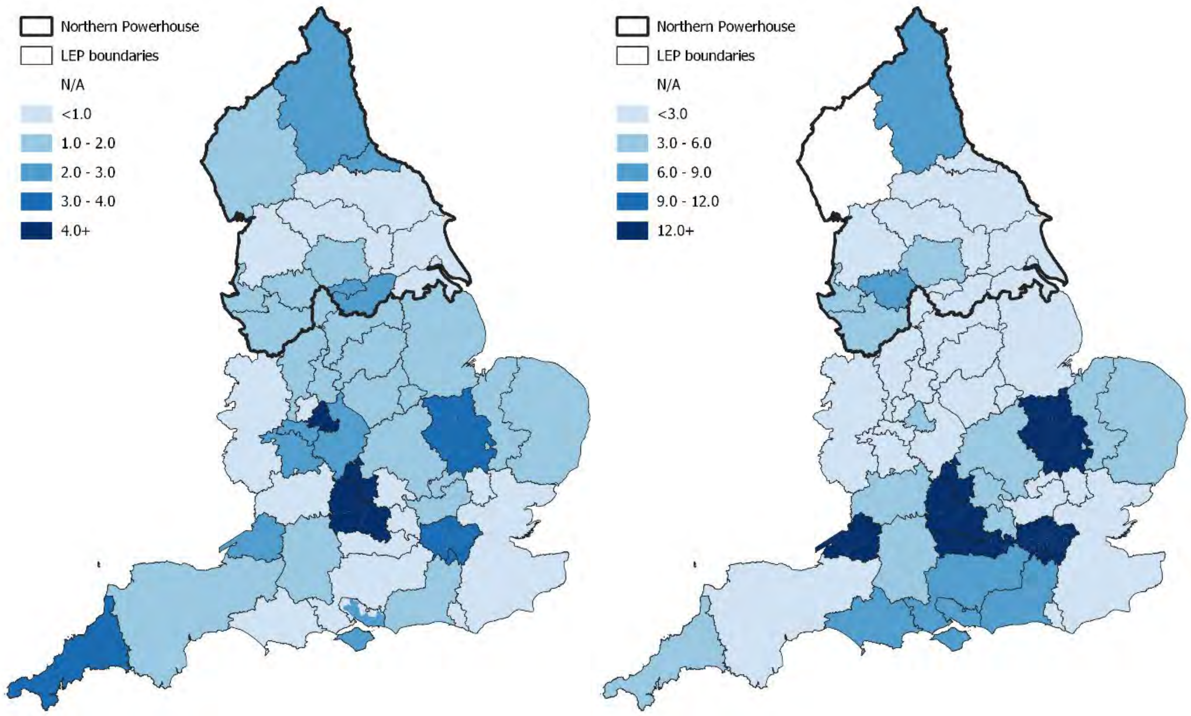
Table 3.3.12: Summary of support systems indicators

	Incubators/accelerators (per 10,000 businesses)	VC investment cases (per 10,000 businesses)
Cheshire and Warrington	1.8	4.5
Cumbria	1.1	0.0
Greater Manchester	1.7	6.6
Humber	0.3	2.1
Lancashire	0.4	2.7
Leeds City Region	2.0	3.3

Liverpool City Region	1.5	3.6
North East	2.9	6.3
Sheffield City Region	2.5	2.8
Tees Valley	2.2	2.7
York, North Yorkshire	0.6	2.2
North of England average	1.6	4.1
National average	2.0	10.8
LEP high	6.7	28.9
LEP low	0.3	0.0

The spatial incidence of incubators and accelerators varies across the country, but there is a notable clustering of activity around Oxford and Cambridge. London dominates the offer around the South East, whilst Birmingham and its surrounding area have a strong, less centralised network. Cornwall stands out as an interesting outlier, likely reflecting the significant levels of enterprise-related funding directed into the county over recent years. In the North, most areas are typically underrepresented in terms of their incubator and accelerator offer, though Sheffield, the North East and the Tees Valley all have incidences exceeding the national average.

Figure 3.3.18: Incubators/accelerators (per 10,000 businesses, left hand side), and VC investment cases (per 10,000 businesses, right hand side)



Source: Nesta, TechNation, CE

In terms of VC investment, London dominates the national picture, accounting for over two-thirds of all VC investment cases in the country (and a likely higher share of the supported value). Strong VC networks are also evident in Oxford, Cambridge and Bristol, with the three cities emerging as key areas of VC activity outside London, attracting associated agents and activity. Increasing activity is also evident along the south coast. Particularly notable though is the comparatively low levels VC activity in the Midlands, even around Birmingham.

Compared to the Midlands, the North has a much stronger and balanced VC offer. Manchester and the North East are two notable clusters, the latter centred on Newcastle in particular, and may reflect the strong tech and start-up-oriented environment in these areas. Liverpool, Cheshire and Leeds also show signs of activity, but away from these areas, particularly in rural areas with low levels of service sector, the number of cases drops significantly.

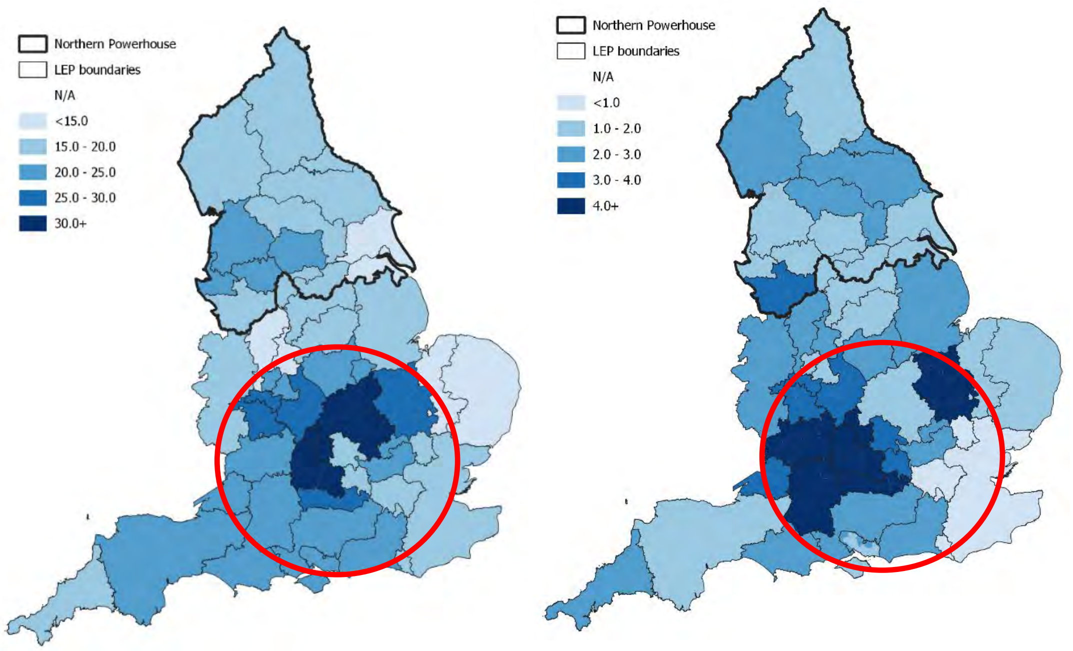
4 Analysis of Indicators

4.1 The National Picture

Analysis of the spatial pattern of the metrics suggest that the performance of the North is not atypical – in fact a broad look at the indicators collected suggests that its overall innovation performance in line with the majority of the rest of England.

However, what can be identified from looking at the maps is an area of central, southern part of the country that performs unusually well across all innovation metrics. This area does not have hard boundaries, but appears to stretch from Bristol in the West to Cambridge in the East, and from Brighton on the south coast, up to Coventry in the Midlands. The area thus covers part of 5 different regions; London, South East, South West, West Midlands, East of England; although equally four of these regions also have areas that don't appear to be part of this high-performance geography (the exception being London).

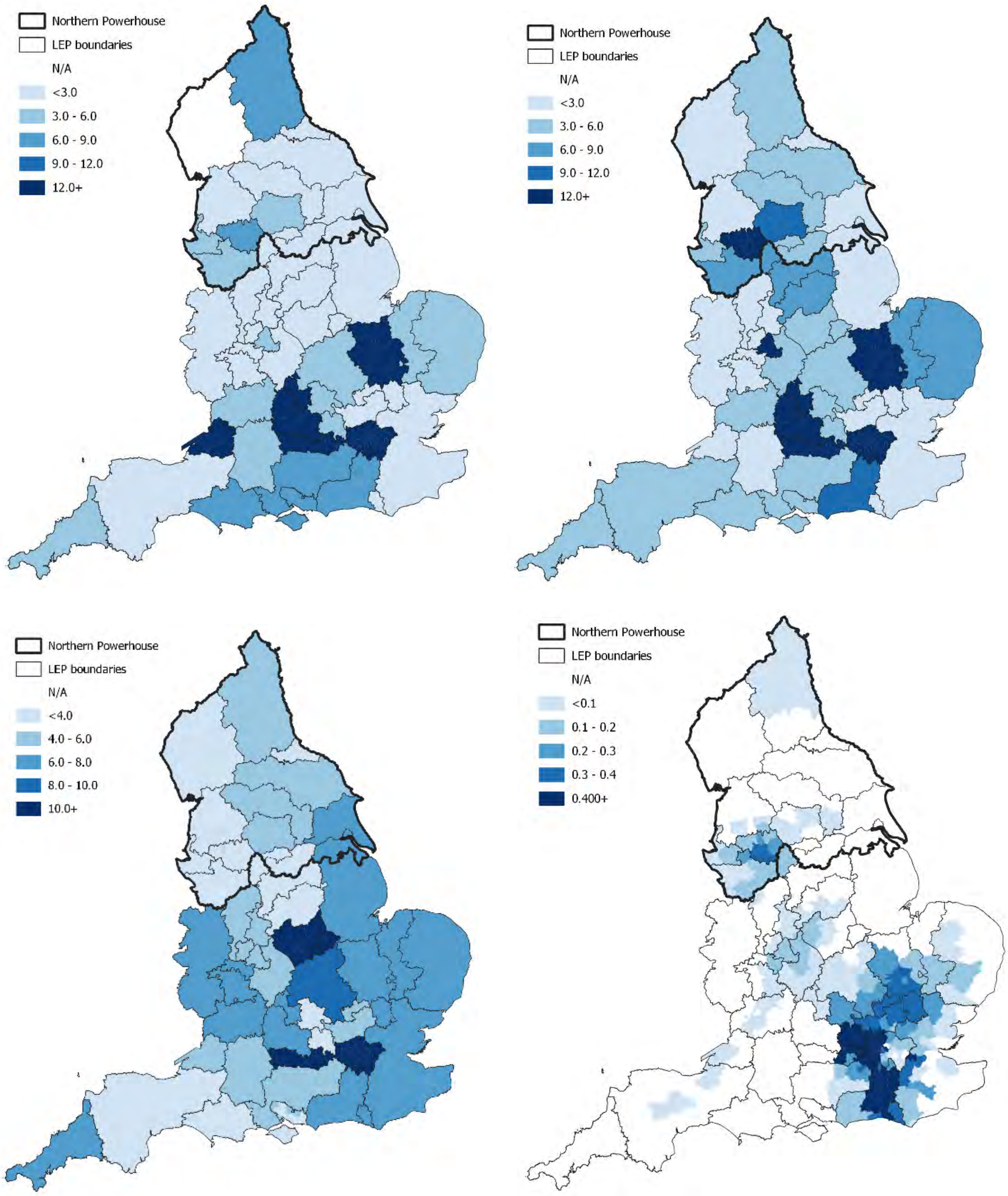
Figure 4.1.2: Proportion of firms undertaking R&D (%), left, unique CPC patents per 10,000 adults, right



Although this report is about the North of England, it is instructive to briefly consider why this area performs so consistently well, and what lessons there are to learn for the North.

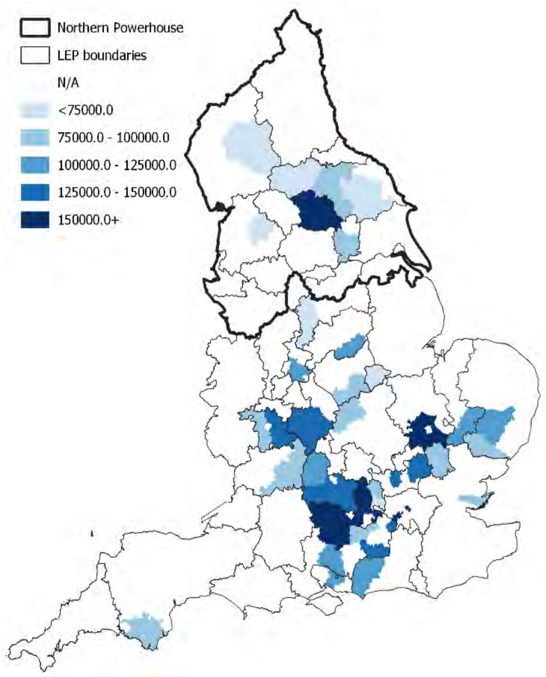
Firstly, proximity to London, and to a secondary degree its surrounding international airports, are of clear benefit. The area benefits from strong involvement with multinational corporations and venture capital. Although much of the innovation activity occurs outside of London, the role of London as a convening and networking hub is clearly crucial. A question that might arise is the extent to which larger cities in the North are able to facilitate innovation in their surrounding areas in the same way.

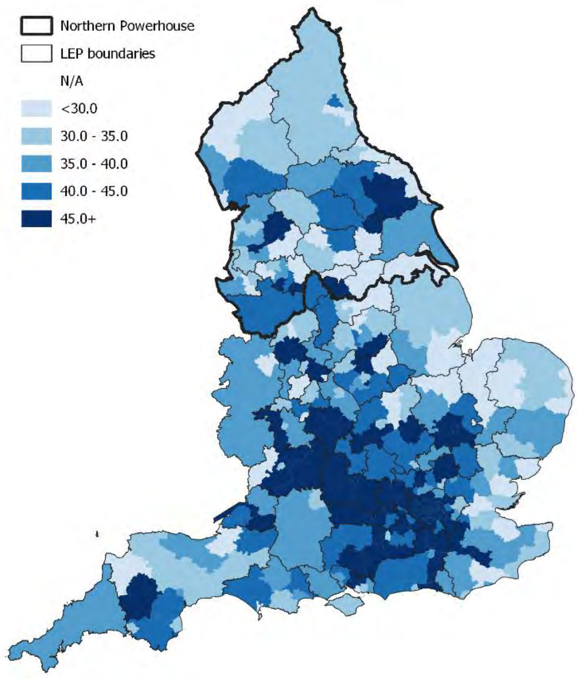
Figure 4.1.2: Benefits of proximity to London: Clockwise from top-left: VC investment cases per 10,000 businesses, science and tech-based 'Meetup' interactions, airport accessibility score, proportion of businesses with overseas head-offices.



Although there are a number of cities spread around this area, including some relatively large settlements such as Southampton and Bristol; as a whole the area is largely rural or suburban in nature, with a range of smaller, historic cities, and market towns. It could be speculated that the advantage this brings is in the variety of lifestyle offers available to mobile knowledge workers both from the UK and from further afield. Indeed, the data shows that this area is particularly adept at attracting and retaining knowledge workers. There are two implications here for the North; firstly, the importance of generating a high quality of life offer, and secondly, the role that rural areas and smaller historic cities can play in the wider innovation system.

Figure 4.1.3: left: Halifax Quality of Life Survey Top 50 places, right: proportion of residents with NVQ4+



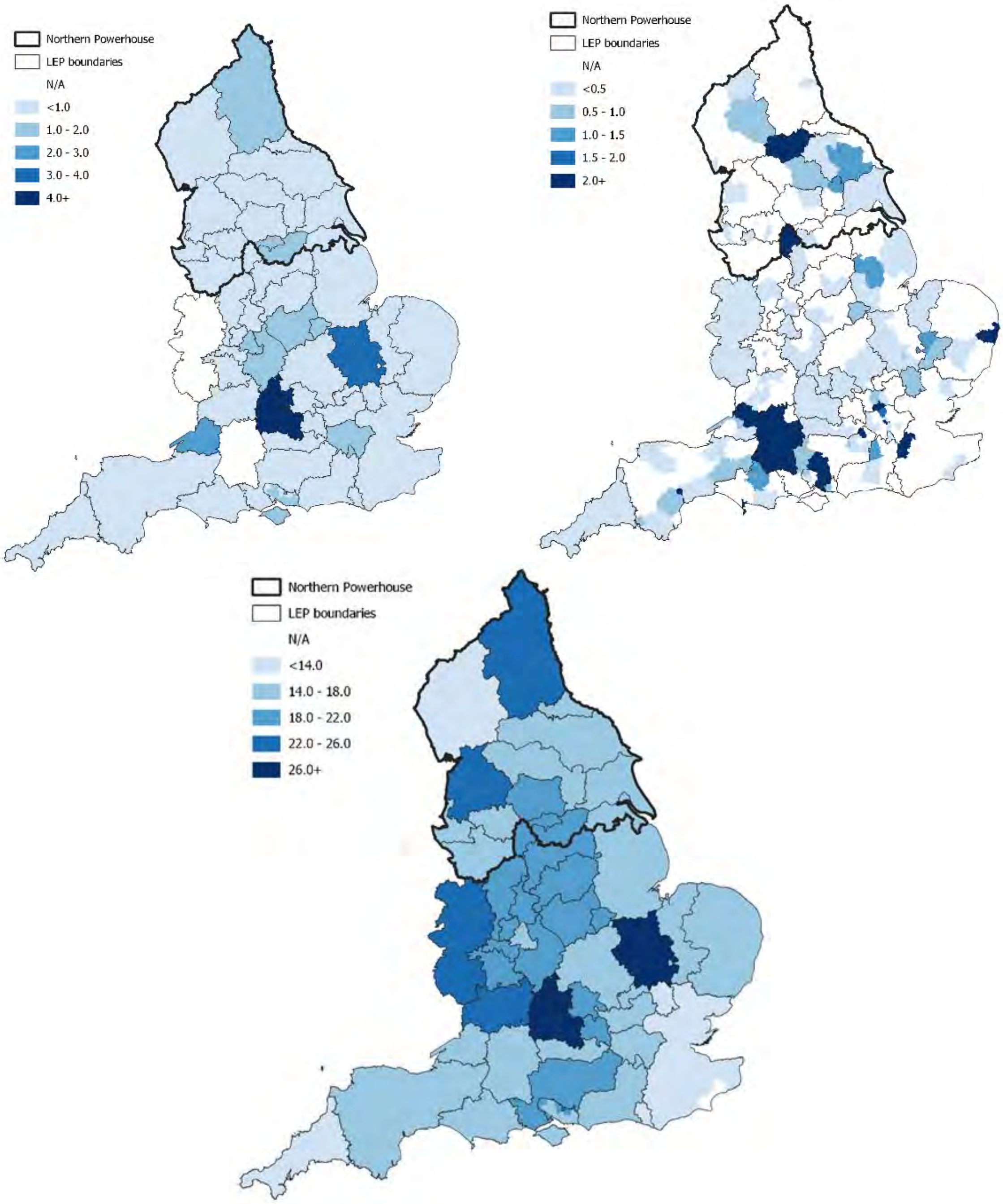


Although the innovation ecosystem is evidently private sector led, the presence of long-established public institutions is also clearly a factor, not just in the generation of knowledge, but in the attraction and generation of knowledge workers, be these world-leading Universities at Oxford or Cambridge, or other public institutions such as DSTL and GCHQ. Whilst the North has its fair share of high-quality research universities, it could be argued that should new publicly funded institutions be required, it should be first in line to host these.

A recent report[79] for BEIS by Cambridge Econometrics identified that a boost to UK R&D expenditure from the current 1.6% of GDP to the stated target of 2.4% would have positive significant effects on long-run national GDP and productivity, with a boost of 2.9% to national GDP by 2040. Furthermore, the study identified a higher long-run GDP impact when R&D is concentrated outside the greater South East. In 2040, the additional positive impact of a more regionally-dispersed R&D expenditure profile is 0.8% of GDP. As the report identifies, regions like the North, with a larger share of manufacturing employment stand particularly to gain; the manufacturing sectors are more trade-focused and operate in more global markets, and additional R&D could potentially give these sectors a competitive edge in a much larger market, leading to larger gains in potential production at both the national and regional level.

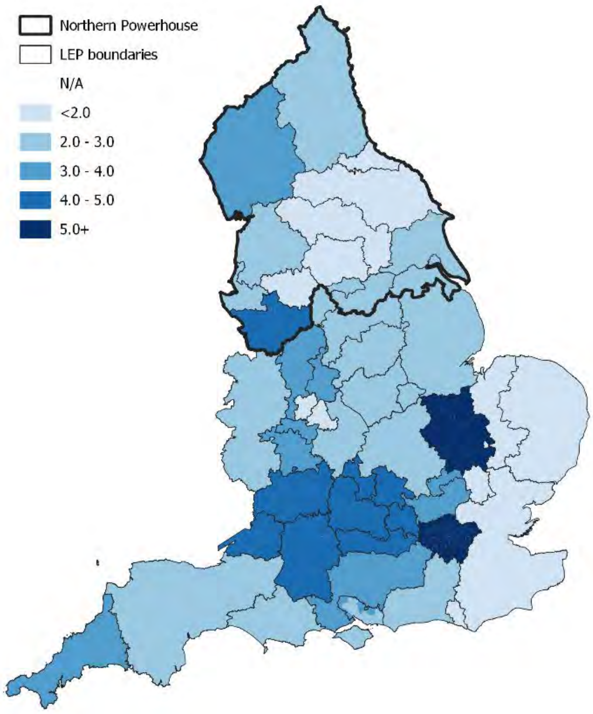
[79]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/897462/macroeconomic-modelling-of-2-4-r-and-d-target.pdf

Figure 4.1.4: Impact of public institutions and funding: University research staff (per 1,000 adults, left hand side), and central government research staff (per 1,000 adults, right hand side) R&D Tax Credit claims (per 1,000 businesses, bottom)



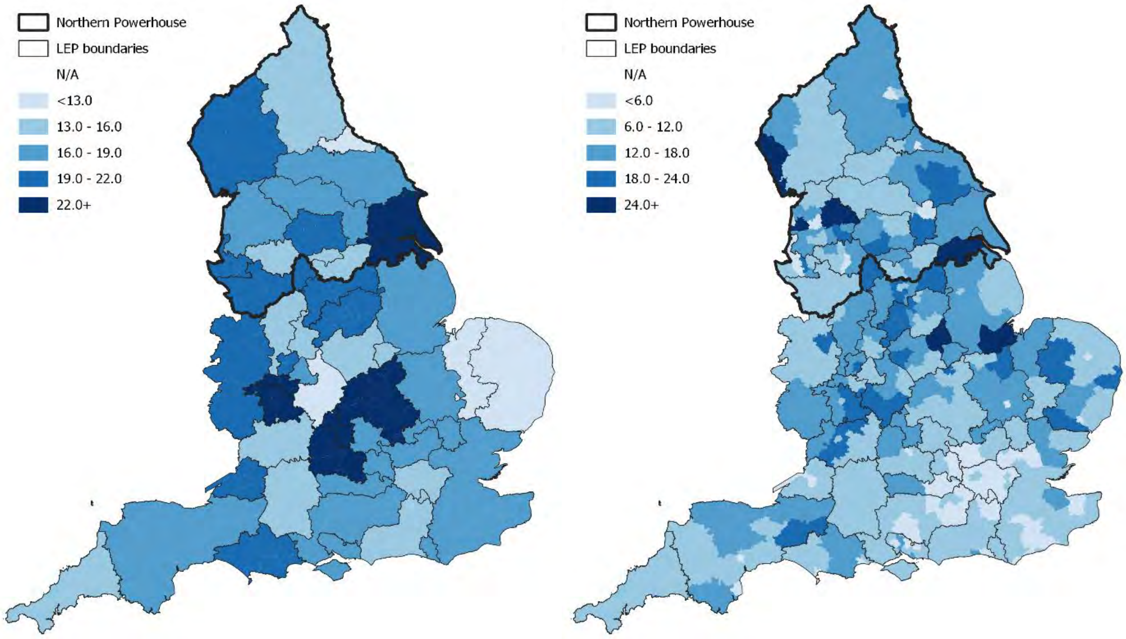
Finally, moving to the question of what innovation as well as why, we briefly touch on the spatial expression of the concept of related variety, that of hierarchies of specialisation. This theory suggests that whilst successful innovation ecosystems both require, and are able to maintain, a diversity of knowledge domains across wider spatial levels, this often hides a pattern of more specialised knowledge production and utilisation at smaller geographies. The key to the success of the wider ecosystem is therefore the extent to which different geographic areas are able to both develop their own specialised niche within the whole, and then collaborate and share information (during all stages of the innovation cycle) with neighbouring areas who have complementary specialisations. A network of knowledge generators, implementors, disseminators and adopters is created across a wide variety of knowledge domains, and through this process, a system-wide related variety is ensured.

Figure 4.1.5: Number of specialisations in research-intensive industries.



We can see from Figure 4.1.6 where the aggregate of neighbouring LEPs in the south of England, each with a handful of knowledge intensive sectoral specialisations, forms a wider, more diversified cluster, and from analysis in Chapter 6 of this report, the extent to which this system seems to be functioning with a high degree of efficacy in the South of the country. The question here, therefore, is what can be done to help areas within the North continue to develop and build on their own specialisations, and then develop the right connections and networks to ensure that the right knowledge is disseminated between the organisations who can make best use of it.

Figure 4.1.6 – % of firms engaging in process innovation (left) and manufacturing and production employment share, % (right)



Whilst the North will never exactly replicate the successful conditions found in central, southern England, it does have its own advantages. It holds its own in process innovation, and has a higher proportion of employment in manufacturing, as we will see in Chapter 5, one of the most important sectors in generating and utilising novel ideas.

4.2 Spatial Patterns across the North

The data presented in Chapter 3 provides a comprehensive view of patterns related to the innovation process, its drivers, and enablers across the North. As the logic map highlights, the processes and the factors that influence them are highly interrelated. The data in the previous chapter reinforces this fact as many of the indicators discussed can help us gain a view of multiple phases of the innovation process and its drivers. This section makes some initial steps towards synthesising these findings through the lens of the logic map and highlighting key patterns, areas of interest, and questions for further study.

Metrics

Taken together, the metrics provide insight into Northern performance through the phases of the innovation process. As these stages are themselves difficult to draw clear lines between, so too does the data blur across boundaries. Still, the suite of indicators that we have chosen to represent and analyse the innovation process allows us to draw out some preliminary findings.

First, and most revealing, is that no one LEP dominates the rankings across the board, and in fact all LEP areas appear in the top-5 for at least two indicators, showing the range and diversity of strengths across the wider region. While, in general, we expect larger metropolitan regions to tend to have higher performance on innovation indicators, this analysis challenges this pattern. Of the more urbanised regions, Liverpool City Region appears to be most consistently in the higher echelons and above national averages showing strong performance in five of eight indicators and in every phase of the innovation process. Leeds City Region also has relatively strong performance figures.

While the performance of less urban LEPs generally clustered around or below national averages, Cheshire and Warrington, Lancashire, and Tees Valley stand out. These appear in the top five rankings, and above national averages, with relative frequency and lead on several indicators. Cheshire and Warrington tops the rankings for patents (value creation) and generally performs well on measures related to diffusion. Lancashire takes second position on firms doing R&D (research and development) and marketing and strategy investment (diffusion). Tees Valley places second in the proportion of firms undertaking marketing and/or strategy innovation (dissemination) and is particularly consistent in its performance on measures of value creation. While Humber does not emerge as particularly strong across the board it does score highly on measures of implementation (value creation) such as intangibles GFCF and firm process innovation.

Table 4.2.1 Innovation Metrics in the North

	Proportion of firms undertaking R&D (%)	Intangible GFCF-output ratio (%)	Proportion of firms undertaking process innovation (%)	Total CPC patents (per 10,000 adults)	Unique CPC patents (per 10,000 adults)	Proportion of innovating firms' sales attributable to innovation (%)	Proportion of firms undertaking marketing and/or strategy innovation (%)	Proportion of firms introducing new business practices (%)
Cheshire and Warrington	5	2	5	1	1		1	3
Cumbria		1	3		3			
Greater Manchester	3					1		
Humber		2	1		5			
Lancashire	2				5	4	2	5
Leeds City Region	4		4			3	5	4
Liverpool City Region	1	4	2	4			4	1
North East		4		3				
Sheffield City Region							3	2
Tees Valley		4		5	4	2		
York, North Yorkshire				2	2	5		

Another pattern that appears to be emerging from aligning these indicators with the logic map are strengths and weaknesses of LEPs in different phases of the innovation process. Table 4.2.1 shows interesting gaps that might be indicative of performance weaknesses in these phases. For instance, Leeds City Region does well on measures of knowledge creation and diffusion but does not rank strongly on patent filings (value creation). Sheffield City Region exhibits strength on measures of diffusion but does not rank in the top five at all in other phases of the innovation process. Humber performs well on value creation measures but doesn't appear in the top five in either knowledge creation or diffusion. Similarly, Greater Manchester only scores relatively highly on two indicators of value creation.

Two points and two caveats are relevant here. First, while Cheshire and Warrington performs well across (nearly) all indicators, for most LEPs there are and patterns of strengths and weaknesses can be interpreted across phases. These gaps may indicate areas where further research is necessary to establish the nature and significance of apparent weaknesses. The fact that there is such variation in performance across indicators in the same phase of innovation suggests that our indicators for that phase may have a low correlation with one another. This can be valuable in diagnosing specific strengths and weaknesses within a given phase of the process of innovation but also might suggest that results should be interpreted with caution. While we do see patterns of strengths and weaknesses across phases of the process, what is not clear (yet) is how significant these patterns may be. As some of these indicators can be applied to different phases it is possible that reallocating the indicator selection, or by obtaining additional sources of data, would change the picture. We should acknowledge that this selection of indicators is somewhat unbalanced. We have one major indicator of knowledge creation versus five for the value creation and two for the diffusion phase of the innovation process. At this stage, we are in the process of adjusting our approach and adding indicators as we validate their robustness for this application. As such, these interpretations should be considered preliminary and open for discussion.

Drivers

As with the metrics, certain patterns emerge from comparing performance on drivers and permit us to understand the degree of influence these variables exert on the innovation process. Here it is important to remember that the logic model suggests that many of the drivers act at all phases of the innovation process but that the nature of these interactions can be qualitatively different at each stage. This type of analysis both acknowledges the multiplicity of effects each driver can exert and explore these nuances to better understand opportunities and target policy.

As expected, while some of the performance patterns across drivers are similar to those in the metrics, there isn't a clear and direct relationship between them. Again, a diversity of strengths is visible, with every LEP area performing well in at least 3 indicators. However, further distinctions arise, and the city regions are generally more prominent across these measures than on the metrics of innovation itself. Greater Manchester stands out as a leader with relatively strong performance across indicators. Leeds City Region and

Liverpool City Region also exhibit strong performance. Cheshire and Warrington and Lancashire continues to rank relatively highly.

Exploring LEP strengths across drivers is also instructive. From this perspective, Cheshire and Warrington emerges as the most consistently high performing LEP across indicators but it has particular strengths in the areas of knowledge base, human capital, and to a lesser extent, innovation culture. Its profile on these indicators tracks with what we would expect given its economic and spatial realities – strengths in R&D spending, particularly among the private sector, high levels of qualifications, and sophisticated business strategy in an area of much lower density than the high-performing urbanised areas. Greater Manchester, by contrast, performs less well on knowledge base measures but quite well on innovation culture and human capital indicators. Places like Sheffield City Region anchored as it is by strong universities and research organisations, also show higher capabilities in areas related to knowledge base and human capital but less strength in terms of innovation culture and interaction across networks. Lancashire exhibits a similar pattern, scoring well on knowledge base, human capital, and relatedness indices and weaker on innovation culture and network interaction. Leeds City Region, which was one of the most consistent for performance across metrics is also quite strong on drivers, exhibiting strength predominantly on indicators related to networks, culture, and relatedness.

Again, there are places that have interesting gaps – that are strong in some indicators but do not score in the top half of the table on others. Liverpool City Region, for instance scores well in most categories but not on measures of relatedness. Greater Manchester looks strong across the board but has an interesting set of gaps in measure of knowledge base. Leeds City Region is similarly weaker on knowledge base and human capital profile indicators. Other places, like Tees Valley, the North East, Cumbria, and Humber have some areas of strength, but no significant patterns stand out other than a slight underperformance on these variables than would be suggested by their rankings in the metrics. We can observe a distinction between urban areas, where R&D spending is more influenced by GERD or HERD, and more rural areas, where business investment dominates.

Table 4.2.2: Drivers of Innovation in the North

	R&D spending-output ratio (%)	Proportion of R&D spending BERD (%)	Proportion of R&D spending GERD, HERD and other (%)	Proportion of residents with qualifications at NVQ4+ (%)	Proportion of firms with skills gaps attributable to introducing new working practices (%)	Technological Entropy	Technological Relatedness	Proportion of innovation-active firms collaborating for innovation (%)	Science and tech-based 'Meetup' interactions (per 1,000 adults)	Proportion of population 'settled' (not moved over past 12-months, %)	Proportion of firms with a business plan (%)	Proportion of firms introducing new methods of work (%)	Business birth rate (per 1,000 adults)
Cheshire and Warrington	1	1		1	2	3	4	3	3		3	2	2
Cumbria	4	3			3								
Greater Manchester			4	3	3	5	2		1	2	4	3	1
Humber		2						1		4	2		
Lancashire		4			1	2	3			5			5
Leeds City Region			5			1	1	2	2	2		1	4
Liverpool City Region	2			4	5			4			1		2
North East			3					5	4				
Sheffield City Region	4		1	4		4	5		5				
Tees Valley			2								5	3	
York, North Yorkshire	3	5		2						1		5	

Table 4.2.3: Enablers of Innovation in the North Enablers of Innovation in the North

	Diversity of sectoral specialisation	Diversity of R&I intensive specialisation	High-growth businesses (per 10,000 adults)	Proportion of businesses with HQ overseas (%)	University research staff (per 1,000 adults)	Business and NGO research staff (per 1,000 adults)	Central government research staff (per 1,000 adults)	Proportion of residents residing in Halifax Quality of Life Survey Top 50 places (%)	Arts, culture and leisure offer (employment per sq. km)	Proportion of premises with ultra-fast broadband (%)	Proportion of premises with indoor 4G coverage (%0	Access to Economic Mass (ATEM) score	Access to airport score	Incubators/accelerators (per 10,000 businesses)	VC investment cases (per 10,000 businesses)
Cheshire and Warrington	3	1	1			1						2	2	5	3
Cumbria	4	2					2	2							
Greater Manchester	2		3	5	3		2		1	2	2	4	1		1
Humber				1						3					
Lancashire	1		5				2	3							
Leeds City Region	5		4	2	5				3	4	1		4	4	5
Liverpool City Region		3			5	4	2		2	5	4	1	2		4
North East		4		3	1	5					3	3	4	1	2
Sheffield City Region		5		5	2		2		4		5	5		2	
Tees Valley						3			5	1				3	
York, North Yorkshire			2	4	3	2	1	1							

Enablers

Enablers function as indirect influences on the innovation process, primarily by creating or enhancing the conditions in which innovation can more easily occur through their impact on wider drivers. As such, in this section we are primarily interested in the patterns that we can observe in the characteristics of these enabling variables across places relative to those observed in the drivers. Employing this lens permits a better, if still preliminary, understanding of what might be influencing the drivers and how and how these differ across LEPs. Again, the initial impression is one of diversity, with strengths spread across all LEP geographies.

An analysis of sectoral specialisations and structures across the region shows considerable variation in the types of industries that are most concentrated in each LEP. While many LEPs have numerous specialisations in consumer services and transport and logistics – linked to ports, rail, and freight movements related to other industry – beyond that, LEP specialisations differ substantially. Cheshire and Warrington, Greater Manchester, Leeds City Region, the North East, and Liverpool City region show greater concentrations and specialisations in knowledge-intensive sectors such as media and technology; business support services; finance, law, and management; and science and healthcare. Sheffield City Region, the Tees Valley, and York and North Yorkshire combine concentrations of public services, education, and social welfare with heavier industries such as manufacturing, extraction and utilities, and logistics. Places like Humber and Lancashire show specialisations in manufacturing and agrifood.

While these sectoral profiles reflect diversity of specialisation, and not necessarily dominant industries in terms of employment, they are among the sectors in which we're most likely to see shaping LEP economies. To a certain degree, this is reflected in the drivers. The places specialising in more knowledge intensive sectors tend to rank more highly on indicators of knowledge base (such as research and development) and human capital (such as qualifications). These also tend to be the places with stronger innovation cultures. Sectoral structure has direct and important effects on technological relatedness although it is important to note that some of the less urbanised LEPs with less traditionally knowledge-intensive sectoral specialisations score highly on these measures (see Lancashire, Humber, and York and North Yorkshire, for example).

Measures of business base structure also exhibit different patterns across LEPs. There is very little overlap in the places that score highly on proportions of high growth firms and multinational corporations. Only the neighbouring regions of Leeds and York and North Yorkshire score within the top 5 on both measures. Interestingly, the less-urbanised LEPs with greater specialisations in heavier industry tend to concentrate more mid-sized enterprises while high growth firms appear to gravitate in greater numbers to the knowledge-intensive areas (York and North Yorkshire and Lancashire are interesting outliers here). Multinationals, by contrast, number highly in places with heavier industry such as Humber and the North East and, perhaps surprisingly, only one city region (Leeds) ranks among the top 5 attractors in this data set.

The effect of these different types of business base structures is observable in data on drivers. For instance, the location of high growth firms also tends to correspond to areas that score highly on human capital (particularly qualifications) and knowledge base. This suggests that there might be a synergistic effect in which high growth firms demand knowledge and human capital inputs that then shape regional profiles on those scores and that those factors are important attractors of firms in this category. There also appears to be significant effect in the areas of relatedness and culture. A similar argument could be made for multinationals and areas with high qualifications although, interestingly, in the North there tends to be less overlap with LEPs that rank highly on knowledge base indicators. This suggests that, contrary to the expectation that multinationals will tend to boost R&D output and productivity the MNE's locating in the North are perhaps less research-intensive or not sufficiently numerous to meaningfully shift the knowledge base. This may also partly explain some of the weakness of places with stronger MNE presence on network measures – such as firm collaboration and employment density – and may reveal an interesting interaction effect related to dominant sectoral structures.

The North of England has many strong universities and public research organisations and, in many cases, these tend to cluster together. Liverpool City Region and York and North Yorkshire LEPs score highly on all three of our anchor institution measures. Sheffield City Region takes second position on higher education and central government research employment. Cheshire and Warrington tops the ranking of research organisation – likely due to the presence of presence of assets along the Cheshire Science Corridor, including Alderley Park. We expect the presence of anchor institutions would influence several key drivers – most notably knowledge base, network, and innovation culture measures. Unsurprisingly, there is a strong overlap between places with higher university and research organisation employment and knowledge base, such as R&D, reflecting the role of research organisations in contributing to knowledge creation activities. Similarly, places with strong universities and research organisations tend to perform well on network measures. The evidence is less conclusive for innovation culture, however, where culture indicators tend to be strongest where strong research entities exist in city regions (Sheffield is an outlier here).

Quality of place was expected to exert an influence on many drivers and, to the extent that it shapes the environment in which economic activity happens, to have interaction effects with all of the enablers. Interestingly, there appears to be little internal correlation between the measures selected for this variable – percent of residents residing in Halifax Quality of Life Survey top 50 places and arts, culture, and leisure employment. In fact, there is high correlation between the latter and urban places, while less urban places score more highly on the residential quality of life indicator. The weakness of these relationships could be a sign of the inadequacy of our selected measures of quality of place. We acknowledge that it is extremely difficult to effectively operationalise quality of life with existing data sets. As such, we have opted to try to cover both residential and social measures. As to the relationship of this measure with drivers, it is difficult to discern a decisive link with any of them but this outcome was expected and is due to the fact that quality of place has a generally more diffuse and indirect impact overall. Despite these limitations, we feel that it is an important variable to include in an analysis of elements of innovation ecosystems.

Connectivity is a crucial enabler of innovative activity. Infrastructure – both digital and transport – helps connect people and businesses and allows ideas and knowledge to flow locally and globally. The more urbanised LEPs tend to score better across all of these indicators of connectivity with Greater Manchester and Liverpool City Region scoring consistently in the upper ranks. Cheshire and Warrington also scores highly on measures related to external connections – access to economic mass and to airports. Weaker entrants on this variable include Lancashire, Cumbria, and York and North Yorkshire which do not score in the top five on any measures of connectivity, and Sheffield City Region, which scored in the top five on a couple of measures (4G coverage and access to economic mass) but was weak relative to other city regions. We expected that connectivity would have particularly strong effects on interaction across networks and also affect knowledge base. Indeed, there is an overlap between the places that score highly on connectivity measures and perform well on network measures. This link is less pronounced but still significant with places with strong knowledge bases.

Finally support structures sustain regions by providing resources and connections for entrepreneurship, scale ups, and commercialisation. The places that score highly on measures of presence of incubators/accelerators are perhaps unsurprisingly those regions supported by Catapults. This suggests that there is a critical mass of support structures in those ecosystems and that while the Catapult may be dominant it is not the only game in town. VC investment is spread relatively evenly between the urbanised Greater Manchester and Liverpool City Region economies and the North East and Cheshire and Warrington. We expect that the presence of deep and robust support systems will positively impact drivers related to innovation culture and network interactions. This appears to be the case, particularly in the case of innovation culture where Cheshire and Warrington, Leeds City Region, and Greater Manchester lead. One exception here is the North East, which scores well on support structure but is largely absent from the top half of the rankings on culture and network interactions.

As with metrics and drivers many questions remain about the significance and magnitude of interaction effects. As the analysis evolves, we can more precisely validate links and query connections that stand out. Broadly, however, many of the links described in the logic model appear to have anticipated effects.

Relationships between Metrics

The correlation table below shows the correlation matrix between the major metrics, drivers and enablers of innovation as identified and operalisationalised.in chapters 1 and 2. We have selected only one indicator for each category, in order to be able to visualise the relationship between all three groups in the same table. The matrix is symmetric.

There are generally positive correlations between metrics, postulated, drivers, and enabling factors. One exception is process innovation, which is not well explained well by these set of drivers. It does, however, positively correlate to areas with high levels of manufacturing.

Table 4.2.4: Correlation Matrix of Metrics, Drivers and Enablers

	Firms undertaking R&D	Firms process innovation	Total CPC patents	Firms marketing/strategy innovation	Firms introducing new practices	R&D spending	Residents qualifications NVQ4+	Technological relatedness*	Collaboration for innovation	Firms with business plan	R&I-intensive sectoral specialisation	Business, NGO research base	Halifax Top 50	ATEM	VC investment cases
Firms undertaking R&D	0.0	0.3	0.6	0.6	0.4	0.5	0.5	0.6	0.7	0.5	0.3	0.5	0.3	0.2	0.5
Firms process innovation	0.3	0.0	0.1	0.3	-0.1	0.1	0.0	-0.2	0.4	0.1	0.1	0.1	-0.1	-0.1	0.1
Total CPC patents	0.6	0.1	0.0	0.3	0.2	0.8	0.5	0.4	0.6	0.3	0.6	0.9	0.3	0.1	0.6
Firms marketing/strategy innovation	0.6	0.3	0.3	0.0	0.4	0.3	0.4	0.5	0.6	0.3	0.2	0.2	0.3	0.3	0.2
Firms introducing new practices	0.4	-0.1	0.2	0.4	0.0	0.3	0.2	0.4	0.4	0.3	0.2	0.2	0.2	0.2	0.0
R&D spending	0.5	0.1	0.8	0.3	0.3	0.0	0.4	0.1	0.5	0.2	0.5	0.9	0.3	0.2	0.5
Residents qualifications NVQ4+	0.5	0.0	0.5	0.4	0.2	0.4	0.0	0.6	0.3	0.5	0.7	0.5	0.6	0.4	0.7
Technological relatedness*	0.6	-0.2	0.4	0.5	0.4	0.1	0.6	0.0	0.4	0.1	-0.1	0.3	0.3	0.1	0.5
Collaboration for innovation	0.7	0.4	0.6	0.6	0.4	0.5	0.3	0.4	0.0	0.4	0.4	0.6	0.2	0.3	0.4
Firms with business plan	0.5	0.1	0.3	0.3	0.3	0.2	0.5	0.1	0.4	0.0	0.4	0.2	0.2	0.5	0.4
R&I-intensive sectoral specialisation	0.3	0.1	0.6	0.2	0.2	0.5	0.7	-0.1	0.4	0.4	0.0	0.6	0.3	0.3	0.7
Business, NGO research base	0.5	0.1	0.9	0.2	0.2	0.9	0.5	0.3	0.6	0.2	0.6	0.0	0.4	0.1	0.7
Halifax Top 50	0.3	-0.1	0.3	0.3	0.2	0.3	0.6	0.3	0.2	0.2	0.3	0.4	0.0	0.2	0.4
ATEM	0.2	-0.1	0.1	0.3	0.2	0.2	0.4	0.1	0.3	0.5	0.3	0.1	0.2	0.0	0.5
VC investment cases	0.5	0.1	0.6	0.2	0.0	0.5	0.7	0.5	0.4	0.4	0.7	0.7	0.4	0.5	0.0

*data missing/incomplete and correlations subject to change

5 Regional Knowledge Spaces

Introduction

This chapter, and the one that follows, present analysis of data relating to the knowledge ecosystem of the UK, and the North of England in particular. This mostly draws on detailed patent data, but also on Innovate UK funding applications and BRES employment data.

This avenue explores some of the questions about the relationship between local and pan-Northern capabilities and future opportunities in product and technology markets, and sheds light on the role different sectors and labour market segments have in this stage of the innovation process.

LEPs have been perennially interested in what their specialties are, primarily as a point of competitive advantage. While in some cases those strengths are obvious – i.e. in cases where there are legacy industries or very large employers – other areas of specialism can be more subtle. Looking at employment LQs alone, a key specialisation measure, does not indicate which firms and sectors are *innovative* and *innovating*. For example, retail typically scores highly on specialisation indicators, but is not a particularly innovative sector.

Patent data can help demonstrate that a small cluster of firms are highly active in patenting or that firms operating at the intersection of two less concentrated industries are creating useful technologies. Using patent data can reveal such patterns, and that empowers decision makers – to target investment, to learn more, to think about how to scale and encourage partnerships.

The key analysis in this report is based on the construction of a comprehensive patent dataset, that allows us to investigate in more detail the existing and growing technological specialisations of each LEP and at a pan-Northern level. There are insights that can be drawn from the technology-space analysis alone, for example identifying potential smart specialisation and diversification strategies based on the concept of proximate technological relatedness, and identifying possible cross-LEP collaboration opportunities based on technological complementarities. However, additional analysis that links the technology/knowledge space to considerations of sectoral and occupational correspondence, can also answer some additional questions, such as:

- What technologies does the North currently specialise in, and how is this distributed across the region?
- How have those changed over time, and how might they change in the future?
- Which local sectors does the analysis suggest are most innovation-active currently, and which might be important in the future?
- What are the pan-northern strengths and opportunities in patent-space? How do these align to the strengths and opportunities of individual LEPs?

5.1 The Northern Knowledge Space

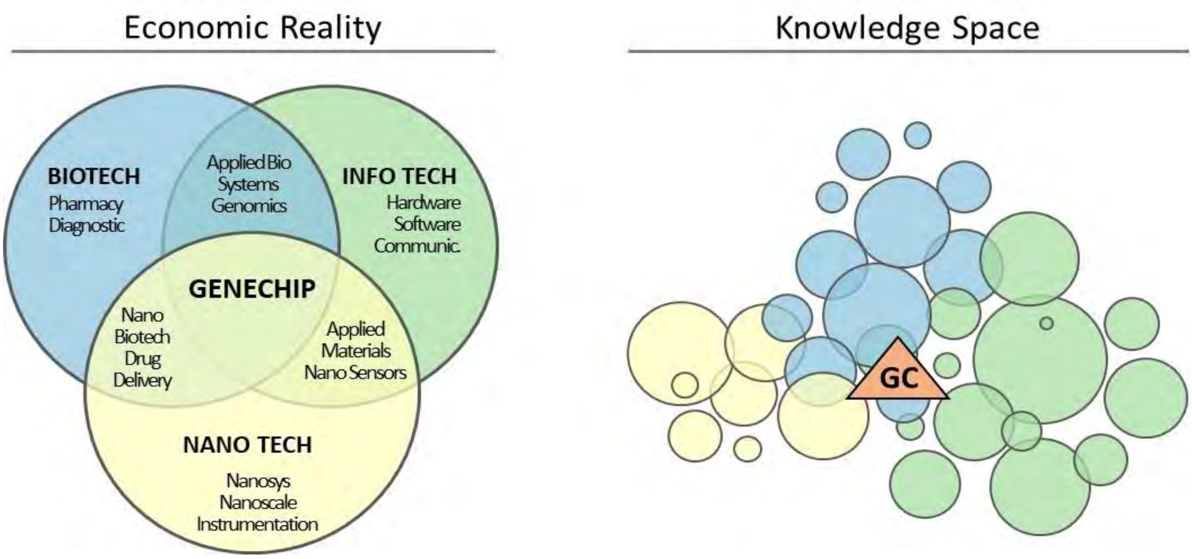
Knowledge is a fundamental building block of innovation, but in evaluating the knowledge stocks of local economies we typically focus on the most visible outputs of flagship firms and universities. Whilst this approach has its benefits, it does not always fully capture the types of knowledge circulating in an economy. It also fails to effectively capture relative quantities or qualities of the knowledge that emerges from economic systems, or permit analysis of how those have evolved over time. Conceptualising economies as knowledge spaces, as measured by patent outputs, provides an alternative methodology that permits academics and policy makers to ask and answer questions about the intellectual and commercial evolution of places and better grasp its gaps and potentials. This method also has its shortcomings; patenting activity only represents a single measure of one aspect of the innovation process; however it is an important and useful one, and combined with other complementary approaches, can offer significant insight into local innovation ecosystems.

Knowledge Space Methodology

The concept of the Knowledge Space was developed with the aim to provide a methodology capable to capture economic realities, translate them into a networked representation of existing capabilities and skills that also allows us to test their inter-connectedness, and also to offer an advanced tool for progressive economic development evaluation and planning purposes.

Figure 5.1.1 shows two different ways of conceptualising a knowledge space and shows how many different sources of knowledge can interact to create innovation outcomes. For example, biosystems engineering or biological systems engineering situated at the top-middle of the illustration is a field of engineering that draws knowledge inputs from both, biotechnology and information technologies. An example of one practical application in this context would be biosensors.

Figure 5.1.1: The Knowledge Space Methodology



Source: Kogler 2016

Needless to say, only places that have the capabilities and capacity of producing both core technologies, or at least found a way to access that specialized knowledge, which is difficult due to the stickiness and the tacitness of economic valuable knowledge[80], will have the advantage to enter into this area of the knowledge space that is driven by recombinant knowledge inputs deriving from two or more sectors. The right-hand side of Figure 5.1.1 displays a networked representation of a hypothetical Knowledge Space that identifies each sector in terms of its quantity (size of nodes) as well as its relative position to other sectors (the distribution among and distance between individual nodes).

Initially applied to cities in the United States[81], and later also to regional economies located in EU15 nation-states[82] this novel framework provides the opportunity to fully investigate the composition, i.e. domain and connectedness, of knowledge produced at various spatial scales. It provides insights into the patterns of local specialization while also offering the opportunity to investigate evolution of knowledge production processes. In this context it challenges the notion that localized knowledge production is purely driven by serendipitous regional trajectories, but rather aims to establish a framework that ensures a transition to planned and organized development pathways guided by evolutionary insights.[83] Following an overview of technological knowledge production in the English LEP regions, and in particular the 11 LEP regions that comprise the North of England, as well as the other three Devolved Nations (Scotland, Wales, Northern Ireland), over the time period 1986-2015 in the following sections, the focus will then shift towards the analysis of the evolution of regional Knowledge Spaces and the opportunity to draw important insights for the development of economic growth strategies.

Measuring Knowledge Production and Diffusion – Patent Data

Knowledge, unlike any other economic good, possesses some unique properties, which in turn makes it difficult to measure and quantify. One quality of knowledge is its public-good character.[84] On the one hand this refers to the non-rivalry character of knowledge, i.e. it does not diminish with use even if it is exploited by many users simultaneously. On the other hand, knowledge is also considered non-excludable, i.e. it is accessible to those who invest in the search for it. All of this promotes the notion that knowledge is subject to increasing returns.[85] Furthermore, knowledge is cumulative insofar that new knowledge builds in prior insights and is added by re-combining elements deriving from the existing stock of knowledge. All of this might explain why knowledge production is considered to follow evolutionary trajectories that

[80] Gertler M.S. (2003) Tacit knowledge and the economic geography of context, or the undefinable tacitness of being (there), *Journal of Economic Geography* 3,75-99.

[81] Kogler D. F., Rigby, D. L. and Tucker, I. (2013) Mapping knowledge space and technological relatedness in US cities. *European Planning Studies*, 21: 1374–1391.

[82] Kogler D. F., Essletzbichler J. and Rigby D. L. (2017) The evolution of specialization in the EU15 knowledge space, *Journal of Economic Geography* 17(2), 345-373

[83] Kogler D. F. (ed) (2016) *Evolutionary Economic Geography: Theoretical and Empirical Progress*. London: Routledge.

[84] Arrow K. (1962) Economic welfare and the allocation of resources for inventions, in NELSON R. R. (Ed) *The Rate and Direction of Innovative Activity*, pp. 609-625. Princeton University Press, Princeton, NJ.

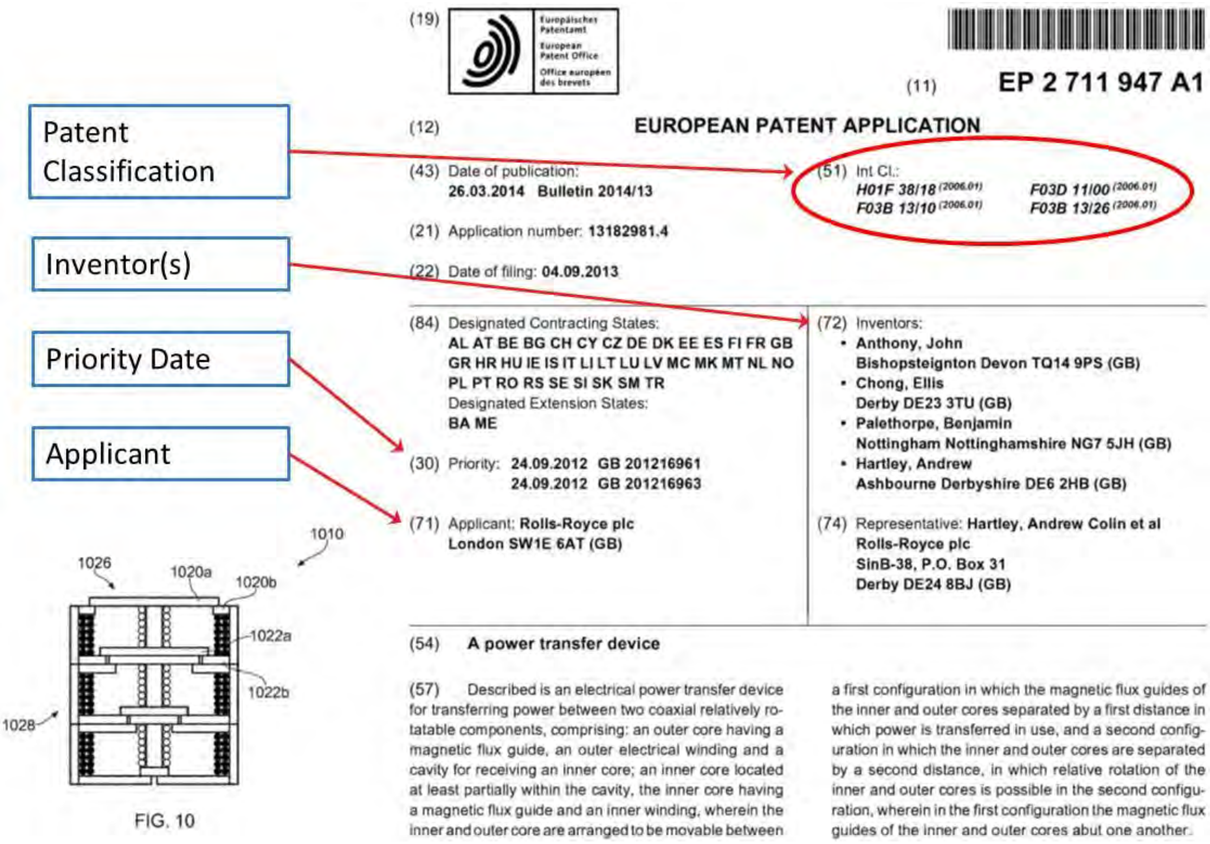
[85] Lucas R. (1988) On the mechanics of economic development, *Journal of Monetary Economics* 22, 3-39. See also, Romer P. M. (1990) Endogenous technological change, *Journal of Political Economy* 98, S71-S102.

allow to delineate past and present patterns of specialization of economic activities in a given place.[86]

Patent data offers an ample opportunity to measure knowledge production and diffusion across economic sectors and their associated entities.[87] Figure 5.1.2 illustrates a random European Patent Office (EPO) patent document and highlights some of the relevant data elements in this context. These include:

- information on the underlying technological knowledge inputs that served as the foundation in the development of a novel product and process of economic value, i.e. the patent classification system;
- data on the associated inventors of the patented invention and there in particular their place of residence at the time of invention;
- various date stamps that indicate the time of the invention; and
- applicant information that designates the original owner and thus most likely initiator and funder of the development processes that has led to a particular invention.

Figure 5.1.2: Example of a European Patent Office (EPO) patent document



Source: PATSTAT, EPO.

[86] Kogler D. F. (ed) (2016) *Evolutionary Economic Geography: Theoretical and Empirical Progress*. London: Routledge.

[87] Kogler D. F. (2015) Intellectual property and patents in manufacturing industries. In J. Bryson J. Clark and V. Vanchan (eds) *The Handbook of Manufacturing Industries in the World Economy*, pp. 163–188. Northampton: Edward Elgar.

In terms of identifying sectors and sub-sectors as illustrated in Figure 5.1.1 as well as those sectors that are the intersection of more unrelated technologies, and that are built on recombinant knowledge, e.g. biosensors as described above, it is especially the patent classification system employed in patent documents that is of particular interest here. Each patented publication is assigned to at least one patent class, but most applications are assigned to more than one class. This in turn allows to identify the underlying technological knowledge that served as a foundation for the development of a novel product or process. In the present example (Figure 5.1.2) it is a combination of specific electrical and mechanical engineering knowledge that has been employed and has contributed to the patented invention.

Information about inventors, and especially their location at the time of invention, as well as about the applicants that have commissioned and engaged in research and development activities in order to generate a patented invention provides further insights in the overall knowledge production process taking place at a given locality.

In summary, all the information found on patent documents provides an ample opportunity to analyse knowledge production processes, which will become the focal point of interest in subsequent sections of this report.

Knowledge Production in UK Regions - Overview

The data to investigate inventions in the UK over the past decades are derived from the European Patent Office (EPO) PATSTAT database.[88] The data collected covers the years 1986 to 2015, grouped in six 5-year periods (Table 5.1.1). Due to a lag between the time of a patent application and its subsequent publication, i.e. due to the length of the examination process, most recent years are not considered here. Nevertheless, because technological change is guided by evolutionary principles this does not constitute a major problem in terms of indicating most recent trends. Also, the time lag between a patent application and the subsequent application of the novel product and/or process in the marketplace further justifies this approach. All years listed refer to priority dates of patents, i.e. the time the invention took place.

Table 5.1.1: Timeframe of the analysis

Period 1	**1986-1990**
Period 2	1991-1995
Period 3	1996-2000
Period 4	2001-2005
Period 5	2006-2010
Period 6	2011-2015

Patents are allocated to countries and regions based on fractional inventor counting. Essentially, if a patent was developed by 3 inventors who at the time of invention resided in 3 different localities, only one-third of that patent is

[88] For further details please refer to: https://www.epo.org/searching-for-patents/business/patstat.html#tab-1 [accessed, May 25th, 2020].

allocated to those respective jurisdictions. This is a common way of allocating patenting activity to spatial units.[89]

Table 5.1.2 indicates the number of patents developed by inventors located in all the UK regions at the time of invention.[90] Looking at the trend over the 30-year period (1986-2015), an average of 21% of all UK patents were developed by inventors residing in the North of England.

Table 5.1.2: Number of patents developed in different areas of the UK, based on inventors' place of residence at time of invention

	1986-1990	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015
England	13,566	12,812	18,974	20,860	20,110	14,966
Of which North of England	**3,571**	**3,520**	**4,519**	**4,701**	**4,459**	**3,060**
Northern Ireland	95.7	96.7	186	290	349	316
Scotland	766	879	1,447	1,682	2,014	1,193
Wales	410	472	678	690	665	575
Northern share of UK inventions	**24%**	**25%**	**21%**	**20%**	**19%**	**18%**

Source: PATSTAT, EPO; author's calculation

It is evident that there has been a slow but steady decline in patents produced by inventors located in the North over the observed three decades, while LEPs in the rest of England, as well as regions in Wales, Scotland and Northern Ireland show an initial growth trajectory up to mid-2000s while then entering a state of decline. The relatively lower patent numbers observed in the final period (2011-2015) could potentially be the result of some missing data that has not been published yet due to the application-grant lag issue highlighted previously. Nevertheless, while the magnitude might not be absolute accurate the observed trends are undeniable. Kogler et al (2017) confirm this, showing that some UK NUTS2 regions among all the EU15 regions are the ones that have declined the most in terms of patent output over the past decades.

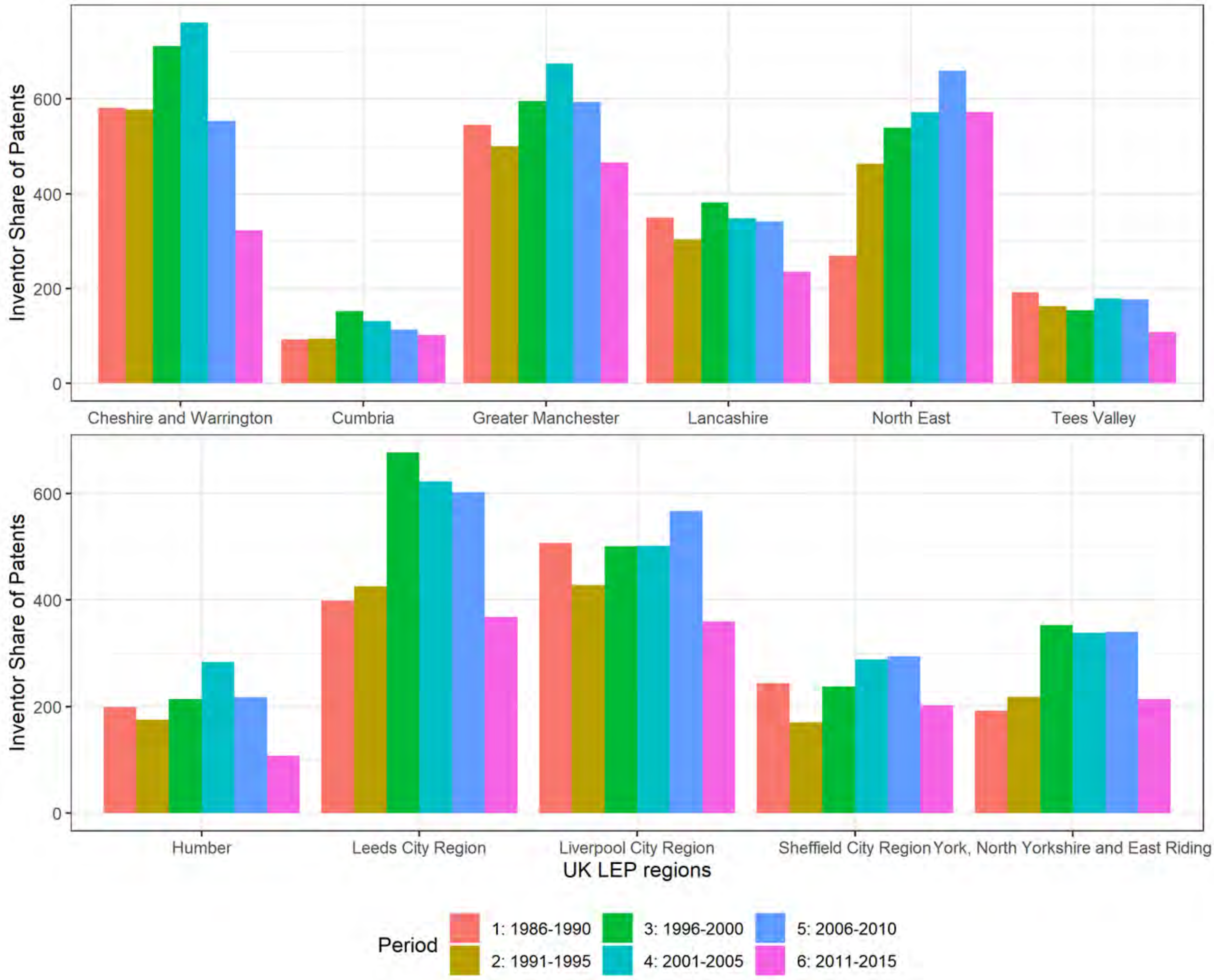
Figure 5.1.3 shows the distribution of patents developed by inventors residing in the North of England. Cheshire and Warrington, and Greater Manchester are the top performing regions in terms of patenting activity. Compared to those regions, Cumbria and Tees Valley have a smaller number of patents.[91]

[89] Kogler D. F., Rigby, D. L. and Tucker, I. (2013) Mapping knowledge space and technological relatedness in US cities. European Planning Studies, 21: 1374–1391.

[90] From this point onwards the report will frequently refer to UK regions, which in the present context are all 38 English LEP areas + NUTS2 areas of the other devolved nations. Similarly, it will also refer to the "study area", "focus regions", "regions of interest", all of which comprises the 11 Northern LEPs that are of the main interest in the analysis that follows.

[91] Please note that while we certainly observe a declining trend among all 11 regions in the final time period (2011-2015) partially this can be attributed to truncation in the data. As mentioned previously, the lag between patent application and when the record is published by the patent authority can be substantial. Thus, even as very recent available data are utilized in the present study numbers in the final time period will be corrected

Figure 5.1.3: Number of patents produced in the Northern LEP regions over time (1986-



Source: PATSTAT, EPO; author's calculation

Inventions by technology category

As well as date and location of invention, patent data is also classified by technology class. Over time several different patent classification systems were employed across global patent offices. More recently it has been the International Patent Classification (IPC) standards developed by the World Intellectual Property Organization (WIPO) that has emerged as an international standard.[92] Subsequently, it was a joint partnership between the United States Patent and Trademark Office (USPTO) and the European Patent Office (EPO) that led to the development of the Cooperative Patent Classification (CPC) system, with is essentially substantially based on the IPC system.[93]

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slightly upwards as time passes and more data will become available. For the purpose of the present study, that is more about evolutionary trends, patterns of specialization and diversification, and an analysis of potential growth areas within the individual LEP knowledge spaces, rather than a benchmarking exercise, there are no significant issues that arise due to the potential truncation of data in the end period.

[92] For an overview of the International Patent Classification (IPC) system, see: https://www.wipo.int/classifications/ipc/en/ [accessed, May 25th, 2020].

[93] For an overview of the Cooperative patent Classification (CPC); see: https://www.cooperativepatentclassification.org/about.html [accessed, May 25th, 2020].

Each CPC classification term found in EPO patent documents consists of several hierarchical elements. The first digit is a letter and is labelled the “section symbol”. For example, “C” stands for the “Chemistry and Metallurgy”. The CPC scheme is organized in 9 sections, i.e. “A” to “H”, including a “Y” section that indicates emerging cross-sectional technologies.[94] The section is then followed by a two-digit number, which is referred to as the “class symbol”. For example, “C01” represents “Inorganic Chemistry” in the “Chemistry and Metallurgy” section. The final letter then at the fourth digit of the code stands for the “subclass”. Following on from the previous example, “C01B” represents “Non-Metallic Elements; Compounds Thereof”. There are roughly 650 unique technology classes at the CPC 40-digit level.[95] The analysis presented below will utilize this level of CPC definition while the figures presented will use a colour scheme that corresponds to the section symbols.[96]

The following maps show the distribution of patenting activity for two of the eight sections (Chemistry & Metallurgy and Textiles & Paper) over the time period 2001-2015, for LEP areas of England, and nations of Great Britain.[97] Note that as these are absolute numbers over this period, they are not scaled to either total population or total inventions, hence do not capture or represent specialisations. They do, however, provide a useful visual overview as to the different distributions of patenting activity across the UK for different technological sections.

From these maps, we can see that the highest producers of patents in Chemistry and Metallurgy in the UK, in absolute terms, are South East LEP, Oxfordshire, Cheshire & Warrington and Scotland, followed by Liverpool City Region and North East LEP. High levels of patent production in textiles and paper originate in D2N2, Liverpool City Tegion, Greater Manchester, and Lancashire, followed by Wales, London and North East LEP.

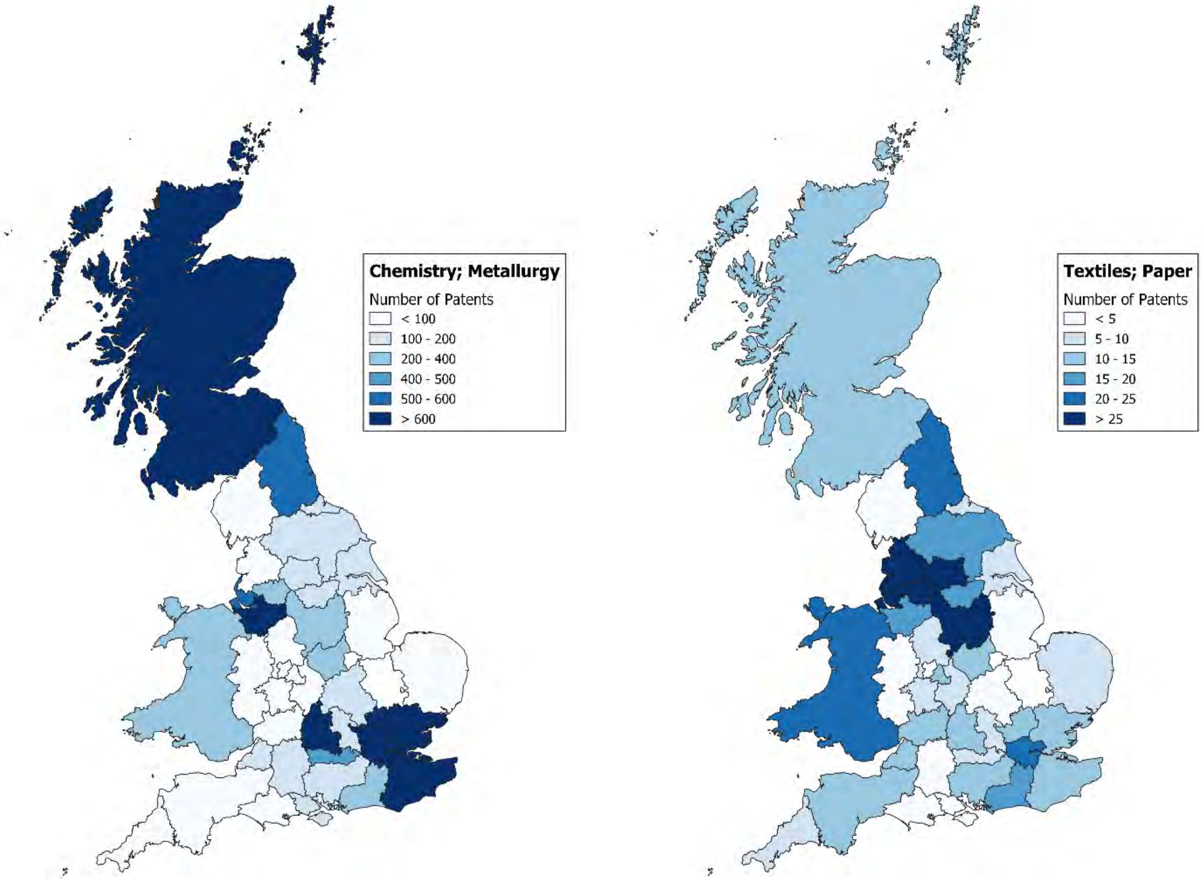
[94] Appendix C1 presents the top 10 LEP areas for each of the sections A-H.

[95] For a full list of the CPC scheme and CPC definitions, see: https://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions/table.html [accessed, May 25th, 2020].

[96] For a detailed description of the underlying Knowledge Space methodology as well as published examples please refer to Kogler et al. (2013; 2017; 2019), Kogler and Whittle (2018) and Buarque et al. (2020).

[97] Maps for all eight sections are provided in Appendix C2.

Figure 5.1.4: Total number of patent co-inventions by GB nation and English LEP for the 2 of the 8 technological sections (2001-2015)



Source: PATSTAT, EPO; author's calculation

Technological specialisations within the North

A better way to identify relative specialisations than studying raw totals is to create location quotients (LQs), that measures the relative specialisation of a LEP in a given metric compared to the national average.

Before looking at the specialisations of individual LEPs, it is informative to identify broad specialisation patterns at the level of the North. Here we compare the Northern region with two other areas of England, comparable in size and, to a lesser extent, coherence of vision: the Midlands, and the South (excluding London). Rather than maintaining focus on the eight broad technological sectors, we dig deeper, looking at the next level of technology classes, of which there are around 120.

The three charts below show the top 20 technology classes by location quotient and patent count for three sub-areas of England chosen: the North, the Midlands, and the South (excluding London) for the period 2001-2015.[98] Although there are exceptions, the differences in technological specialisations of the three regional knowledge spaces become more apparent:

- In the North (Figure 5.1.5), the bulk of the top 20 specialisations are in chemistry, materials, textiles or process engineering
- In the Midlands (Figure 5.1.6), the majority of specialisations are in heavy industry and engineering, metals, pumps and engines

[98] See Appendices C3 and C4 for analysis of individual LEP areas in the North of England.

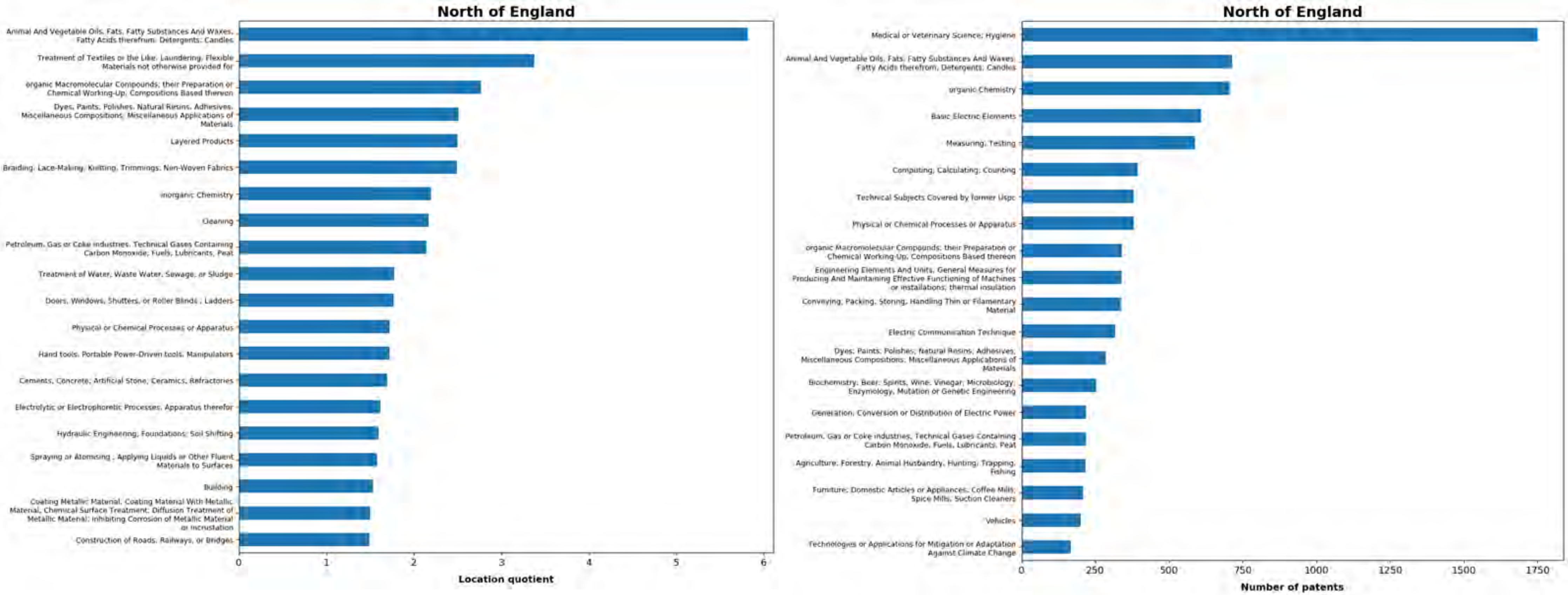
- The South (excluding London – Figure 5.1.7) is quite different again; here the specialisations are in physics, electronics and computing.

These results do not necessarily contradict the concept of the North's key capabilities being in advanced manufacturing, energy, health and digital; however they are suggestive of the relative strengths of those capabilities (compared to the wider national innovation ecosystem) in this particular aspect of innovation, some strengths from outside of that categorisation, and the sub-categories of advanced manufacturing in particular within which the North appears to produce the most new knowledge.

Further questions of importance here are those of complementarity between knowledge domains, both within the North, and between the North and the other major sub-national regions.

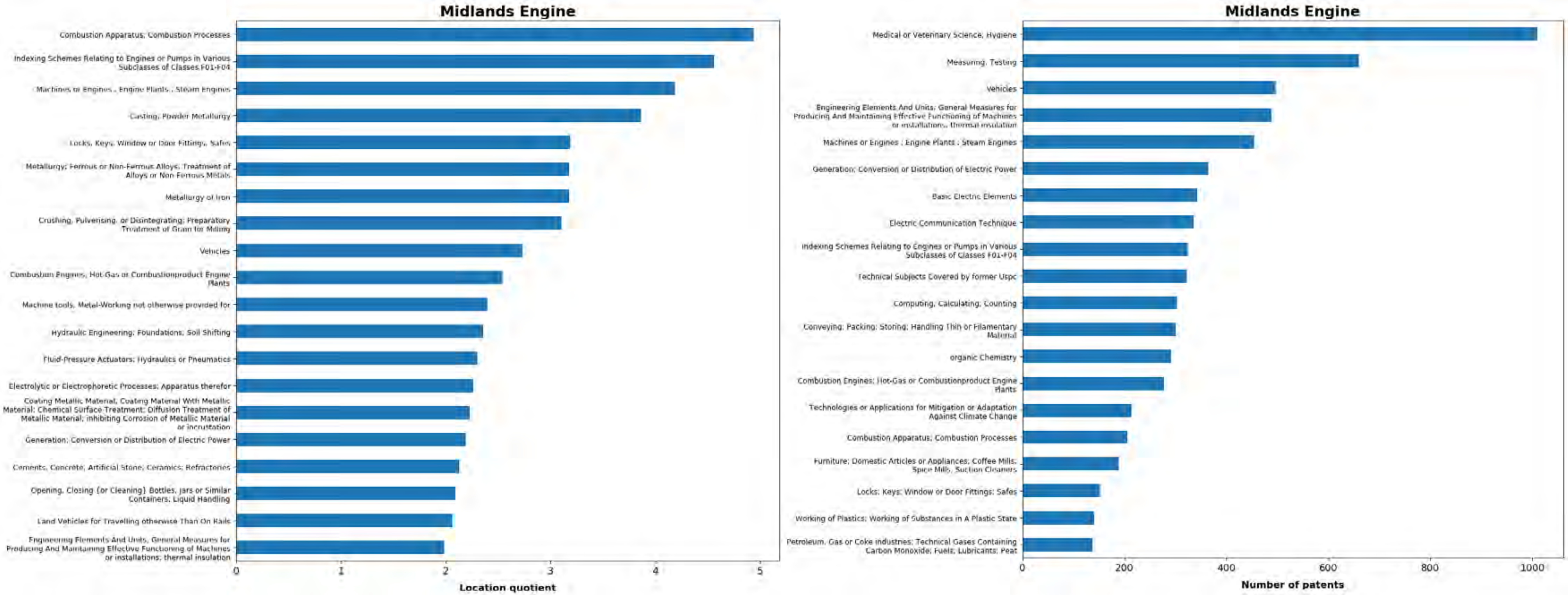
Further analysis of LEP-level patent data is required to identify the level of heterogeneity between individual LEP knowledge spaces within the North.

Figure 5.1.5: Top 20 technology classes by location quotient (left) and patent count (right) in the North of England



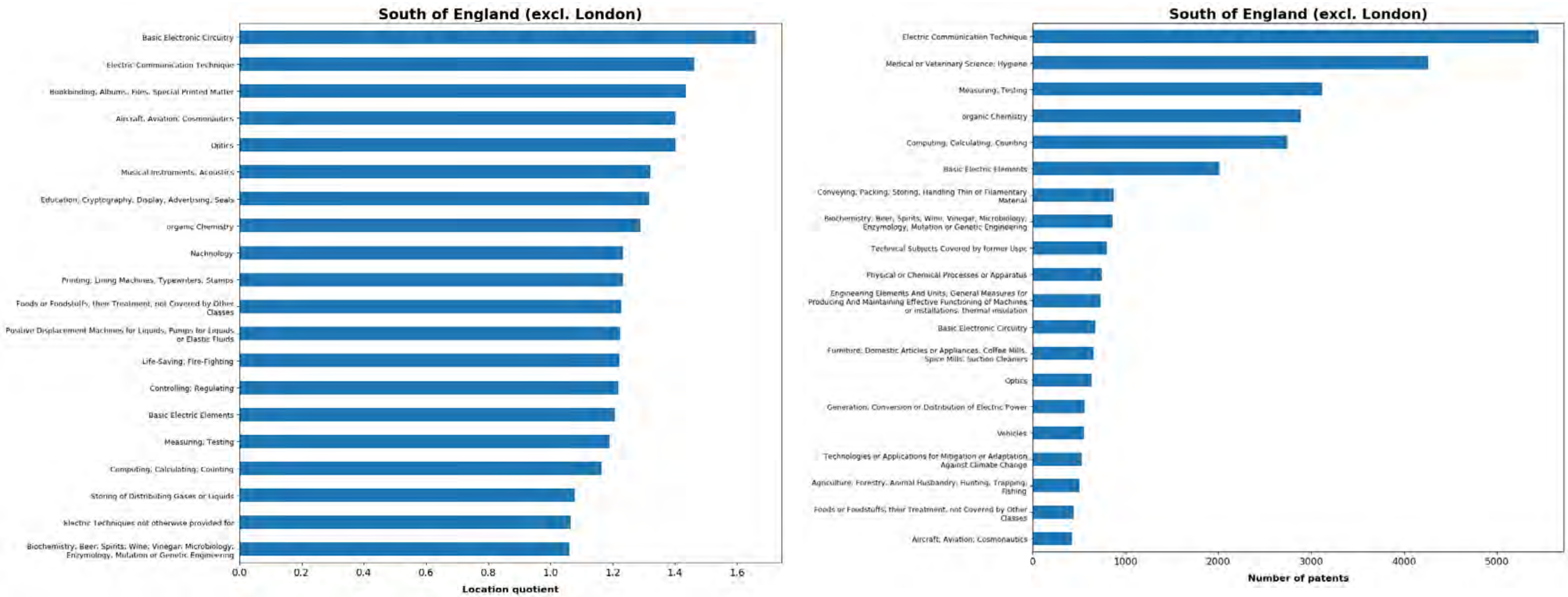
Source: EPO, PATSTAT; author's calculations

Figure 5.1.6: Top 20 technology classes by location quotient (left) and patent count (right) in the Midlands Engine



Source: EPO, PATSTAT; author's calculations

Figure 5.1.7: Top 20 technology classes by location quotient (left) and patent count (right) in the South of England (excluding London)



Source: EPO, PATSTAT; author's calculations

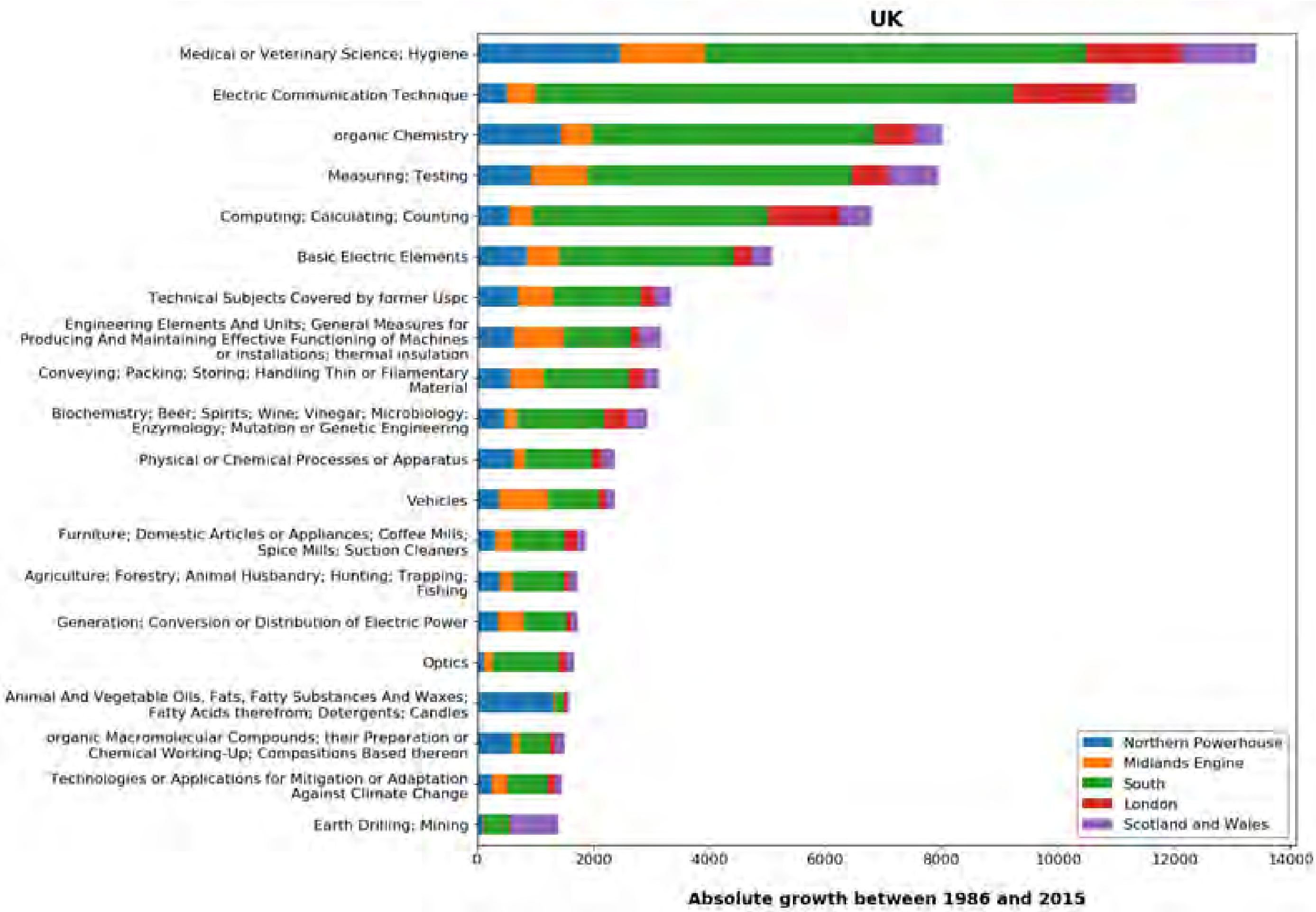
Growth in patents over time

One potential indicator of future growth potential is to identify technology classes that have grown the most strongly within the UK over the past 25 years. This also sheds light onto the relative changes in the Northern knowledge space compared to the wider UK ecosystem over this time period.

Figure 5.1.8 shows the 20 fastest growing technologies in terms of total patent numbers in the UK.[99] Growth is measured as the difference in total patents produced between the periods 1986-1990 and 2011-2015.

At the UK level, the top six technology classes stand out: medical or veterinary science & hygiene; basic communication technique; organic chemistry; measuring & testing; computing, calculating & counting; and basic electric elements. This reflects the UK's growing specialisation in life sciences and digital.

Figure 5.1.8: Contribution of different subnational areas to UK patent growth between 1986-90 and 2011-15 for the 20 fastest growing technologies



Source: PATSTAT, EPO; author's calculation

The strength of the South of England in driving forward innovation across the UK is evident in the above figure, particularly in electric communication technique, and computing, calculating and counting. The North's relative

[99] The fastest growing technologies in the 11 Northern LEP areas are illustrated in Appendix C6.

strengths line in medical or veterinary science and hygiene, organic chemistry, and animal and vegetable oils is evident.

5.2 Evolution of the North's Knowledge Space

In this section of the analysis, attention will be given to the evolution of the Knowledge Space of the North of England. The Knowledge Space methodology, introduced above, serves as the foundation to provide a more contextualized and place specific overview of technological knowledge production than what is possible with traditional innovation metrics such as simple patent data indicators that have been used in the past.

Knowledge space cluster diagrams can be derived in which specific technology classes are shown as nodes within a network. Patents often span several classes, and the shape of this network is defined by the number of times different classes to appear on the same patent; ie the more times they appear together, the more closely they are depicted on the cluster map. These diagrams, while a little chaotic at first, provide a fascinating visual representation of how knowledge spaces and, by extension, economies have changed. These trends over time are particularly useful for pinpointing emerging (and declining) technology classes and understand propensities to co-locate.

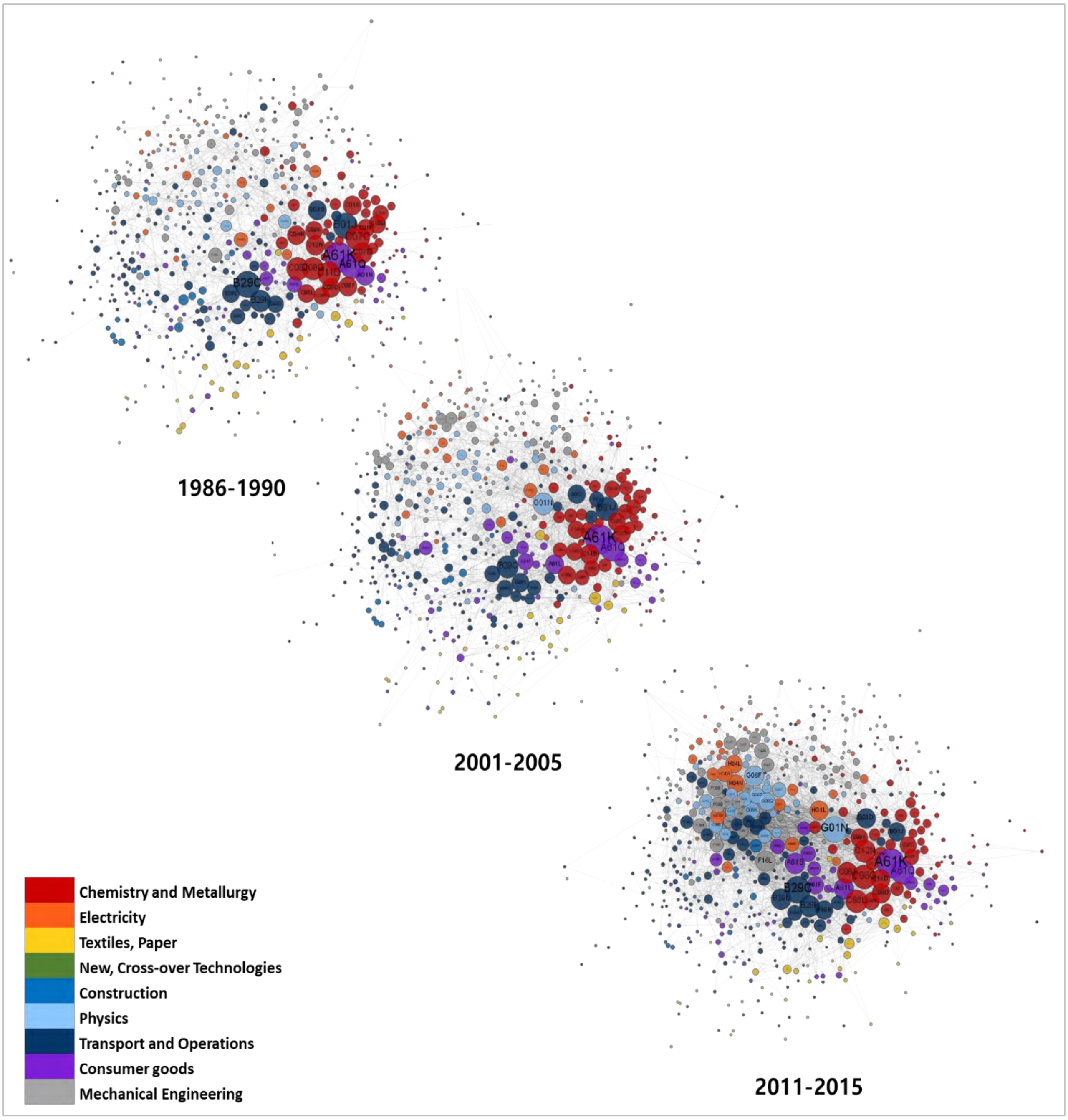
Changing Patterns of Technological Knowledge Production in the North of England

Figure 5.2.1 displays the Knowledge Space (KS) for the North as a whole for three time periods: 1986-1990, 2001-2005, and 2011-2015. First, it shows that a substantial amount of possible CPC classes are present. Second, some nodes are more dominant in terms of their size than others. The size of a node indicates how frequent a specific CPC class was utilized in the development of patented inventions in a time period. Third, it provides an idea of the relative position and clustering of technology classes.

At the edges of the KS one can see not only smaller nodes, but also those who are relatively isolated from the rest of the space. These classes not only are used infrequently as knowledge inputs for the development of novel products and processes, but also are not well connected to the rest of the KS. In other words, they are rarely used, and when used then not much in combination with other nodes as indicated by co-classification on single patent documents. Lastly, it allows to visually track the trajectory of technological knowledge production in the Northern economy.

In terms of the clustering of sections, it is clearly visible that these tend to cluster together within the section, but then also that certain sections seem to agglomerate with other specific sections. For example, the Chemistry and Metallurgy section is co-located with Consumer Goods classes while the Electricity section is in close locational proximity to Physics. Dense areas of the Knowledge Space where nodes of different sections cluster together, or even overlap, are the areas of recombinant knowledge production that have high potential of generating more advanced, perhaps even breakthrough, inventions.

Figure 5.2.1: The Evolution of the Knowledge Space in the North (1986-1990; 2001-2005; 2011-2015)



Source: PATSTAT, EPO; author's calculation

One of the main insights from the above diagram is the way in which the cluster patterns develop over time. In the period 1986-1990, there is a clear cluster to the lower-right of the map, that encompasses a number of related technological classes spanning chemistry and metallurgy, consumer goods, and process engineering ("operations and transport"). This cluster remains visible through all time periods and is a clear example of a long-term specialisation of the region.

As we follow the cluster map through space, we see a second cluster emerging to the upper-left portion of the diagram, focussed around physics and electricity. This is perhaps an example of an emerging strength in the region. The possibility of these two clusters joining together is particularly promising.

There are some other rather visible characteristics that can be easily detected when inspecting the Knowledge Spaces of the 3 time periods. The number of nodes, as well as the density of the space, appears to increase. Furthermore, some nodes either gain on centrality or lose their relative central position and get pushed to the margin over time.

Table 5.2.1 shows the top 5 subclasses in each technological category in the North of England for the period 2001-2015.[100] We see, for example, that *Human Necessities* is dominated by medical or veterinary science & hygiene, Other classes are more evenly distributed.

The current specialisations and historic evolution of the North's knowledge space are clear to see; a key question for further analysis is to identify how they knowledge space might continue to evolve, and the role of policy makers in shaping this.

[100] For a similar table with the individual LEP areas see Appendix C7.

Table 5.2.1: Top 5 subclasses in patent count by technological class, North of England, 2001-2015. Source: EPO, PATSTAT; author's calculations.

Technological Class	Technological Subclass	Number of patents	Technological Class	Technological Subclass	Number of patents
A: Human necessities	Medical or Veterinary Science; Hygiene	1750.47	E: Fixed constructions	Building	166.68
	Agriculture; Forestry; Animal Husbandry; Hunting; Trapping; Fishing	215.47		Hydraulic Engineering; Foundations; Soil Shifting	72.53
	Furniture; Domestic Articles or Appliances; Coffee Mills; Spice Mills; Suction Cleaners	207.54		Locks; Keys; Window or Door Fittings; Safes	62.35
	Foods or Foodstuffs; their Treatment, not Covered by Other Classes	113.89		Earth Drilling; Mining	61.03
	Hand or Travelling Articles	61.25		Doors, Windows, Shutters, or Roller Blinds ; Ladders	59.30
B: Performing operations; Transporting	Physical or Chemical Processes or Apparatus	380.23	F: Mechanical engineering; Lighting; Heating; Weapons; Blasting	Engineering Elements And Units; General Measures for Producing And Maintaining Effective Functioning of Machines or installations; thermal insulation	339.08
	Conveying; Packing; Storing; Handling Thin or Filamentary Material	337.02		Combustion Engines; Hot-Gas or Combustionproduct Engine Plants	63.53
	Vehicles	201.04		Machines or Engines ; Engine Plants ; Steam Engines	63.07
	Working of Plastics; Working of Substances in A Plastic State	140.87		Positive Displacement Machines for Liquids; Pumps for Liquids or Elastic Fluids	55.34
	Layered Products	103.64		Heating; Ranges; Ventilating	49.99

C: Chemistry; Metallurgy	Animal And Vegetable Oils, Fats, Fatty Substances And Waxes; Fatty Acids therefrom; Detergents; Candles	714.84	G: Physics	Measuring; Testing	587.91
	organic Chemistry	707.39		Computing; Calculating; Counting	394.53
	organic Macromolecular Compounds; their Preparation or Chemical Working-Up; Compositions Based thereon	341.71		Checking-Devices	93.64
	Dyes; Paints; Polishes; Natural Resins; Adhesives; Miscellaneous Compositions; Miscellaneous Applications of Materials	284.59		Education; Cryptography; Display; Advertising; Seals	57.26
	Biochemistry; Beer; Spirits; Wine; Vinegar; Microbiology; Enzymology; Mutation or Genetic Engineering	253.40		Signalling	53.87
D: Textiles; Paper	Treatment of Textiles or the Like; Laundering; Flexible Materials not otherwise provided for	107.17	H: Electricity	Basic Electric Elements	610.34
	Paper-Making; Production of Cellulose	74.68		Electric Communication Technique	317.17
	Braiding; Lace-Making; Knitting; Trimmings; Non-Woven Fabrics	18.31		Generation; Conversion or Distribution of Electric Power	218.80
	Weaving	17.06		Electric Techniques not otherwise provided for	97.77
	Natural or Artificial Threads or Fibres; Spinning	12.17		Basic Electronic Circuitry	37.51
			Y: Other	Technical Subjects Covered by former Uspc	380.73
				Technologies or Applications for Mitigation or Adaptation Against Climate Change	167.63
				Information or Communication Technologies Having An Impact On Other Technology Areas	2.28

Network Analysis

One way of gaining insight into this question is to use network analytical tools to interrogate the role of the major technological sections within the overall Northern knowledge space. In order to analyse the technological knowledge structure of the North, three *network centrality indices* are investigated. The first and perhaps most obvious of these metrics is the **degree centrality** of sections within the patent classification system. This refers to the number of ties a node has, which in the present case is measured via the co-occurrence of technology classes listed together on single patent documents. **Eigenvector centrality** provides a measure of the number of other nodes a node is both direct and indirectly connected to, this is thought to represent the influence of a particular technology class within the knowledge space. Finally, **betweenness centrality** is a metric that counts the number of shortest paths that are connected by a particular node. In other words, the measure reflects the influence of a technology domain over the flow of knowledge.

Figure 5.2.2 illustrates the trajectories of individual CPC sections in the North's Knowledge Space over six time periods.

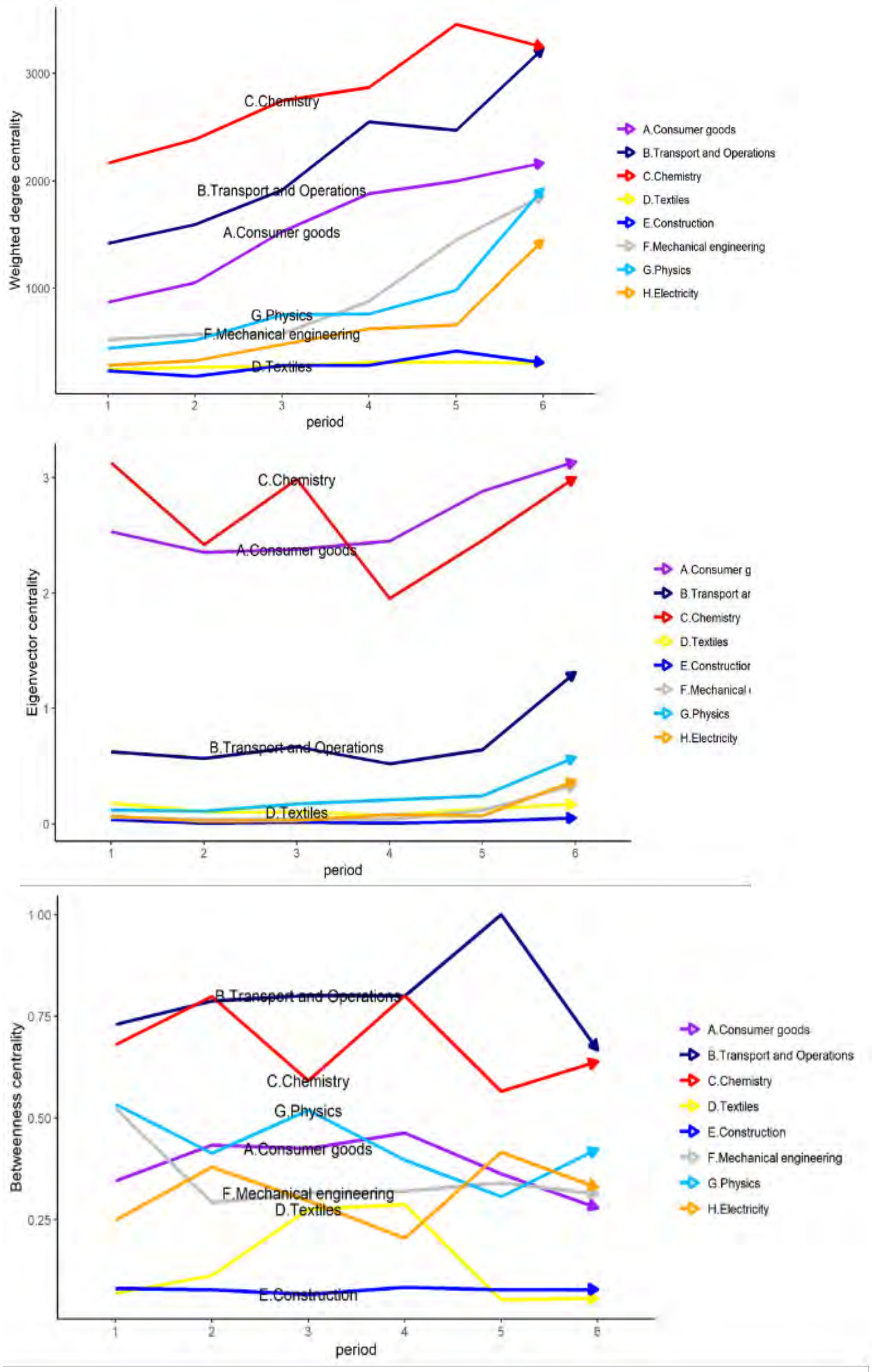
Technological classes in Chemistry are the most central nodes in the Northern knowledge networks. Classes in this section are thus the most connected ones serving as knowledge inputs in the production of novel products and processes along with a variety of other classes belonging to different CPC sections. Given that Chemistry technologies are applied on a wide range of innovations relying on recombinant knowledge deriving from more traditional sections such as Chemical Engineering, but also inputs from more progressive sections, such as Electricity, this might not come as a surprise. Driven by large-scale pharmaceutical production, an industry sector that exhibits a high propensity of knowledge production and patenting,[101] this certainly seems to accurately reflect the technology structure of the Northern economy. In the most recent time period (2011-2015) the influence of Electricity and Physics has increased. This might indicate a transitional phase in the technological knowledge production structure of the regional economy. Perhaps it is a rise of other sectors leading to a diversification of the technology structure, which might be a welcome development in terms of avoiding risk due to overreliance on only one sector and potential negative technological lock-in.

Eigenvector centrality indicates the most influential technology domains in the North's KS as well as their trends over the observed 30-year time period. Chemistry and Consumer Goods are the most influential technology domains in this regard. The gap between these two technology domains compared to others is significant; something that might not be surprising considering that it is inventive entities in these particular knowledge producing domains that dominate the local economy. However, Physics and Electricity related classes[102] are becoming more influential.

[101] Kogler D. F. (2015) Intellectual property and patents in manufacturing industries. In J. Bryson J. Clark and V. Vanchan (eds) The Handbook of Manufacturing Industries in the World Economy, pp. 163–188. Northampton: Edward Elgar.

[102] Such as: G06F – *Electric Digital Data Processing;* G06Q – *Data Processing Systems or Methods, Specially Adapted for Administrative, Commercial, Financial, Managerial, Supervisory or forecasting Purposes; Systems or Methods Specially Adapted for Administrative, Commercial, Financial, Managerial,*

Figure 5.2.2: Measures of centrality of technology sections in the North's Knowledge Space. From top: degree centrality, eigenvector centrality, betweenness centrality



Source: PATSTAT, EPO; author's calculation

In the earlier periods, Transport and Operations (process engineering) as well as Chemistry have been constantly the top bridging knowledge domains. While the rank has not changed much over the observed timeframe, the degree of bridging opportunities, especially with Electricity and Physics, have increased. Figure 5.2.3 highlights the area where most bridging technology classes are located in the 2011-2015 Northern knowledge space.

Supervisory or forecasting Purposes, not otherwise provided for; H04L – *Transmission of Digital Information, e.g. Telegraphic Communication*; H04N – *Pictorial Communication, e.g. Television*

Figure 5.2.3: Northern Knowledge Space, 2011-2015; area of the Knowledge Space where most "bridging" occurs is highlighted in yellow

Source: PATSTAT, EPO; author's calculation

Gaining a better understanding of the evolving roles of different broad sections within the overall knowledge space provides policy makers with significant insight into which technological investments might have the most significant knowledge spillovers and positive externalities for the entire ecosystem. It also identifies opportunities for strengthening the ecosystem; for example, how to deal with the current peripherality of the textiles and paper section.

Opportunities to identify might include:

- Combinations in which textiles developments are combined with knowledge from other technological classes, given the traditional strength in textiles in the region.
- Combinations that bridge the divide between the two clusters; for example between chemistry and electricity, or consumer products and physics.

Evidence of Cross-technological recombinations

The following table shows the number of occurrences of patents filed in the Northern knowledge space between 2011 and 2015, that include two or more classes from different technological sections, and identifies the three LEPs responsible for the most cross-sectional patenting activity. Some combinations are more feasible and common than others, and as such only the top half of the 28 possible combinations are shown.

Table 5.2.2: Cross-sectional patenting activity in the North of England

Technology Combination	Occurrences	LEPs with highest numbers of cross-technology patents
Operations and Chemistry	233.5	Tees Valley Greater Manchester North East
Consumer Goods and Chemistry	198.2	Cheshire and Warrington Liverpool City Region North East
Physics and Electricity	192.1	Greater Manchester Cheshire and Warrington Leeds City Region
Consumer Goods and Operations	123.2	Leeds City Region North East Cheshire and Warrington
Operations and Engineering	106.5	North East Lancashire Cheshire and Warrington
Chemistry and Electricity	93.6	Greater Manchester North East Cheshire and Warrington
Operations and Physics	78.4	Lancashire Greater Manchester Leeds City Region
Chemistry and Physics	75.5	Leeds City Region York and North Yorkshire North East
Operations and Electricity	65.5	Lancashire Sheffield North East
Consumer Goods and Physics	52.3	York and North Yorkshire Cheshire and Warrington Leeds City Region
Engineering and Electricity	50.7	North East Greater Manchester Cheshire and Warrington
Consumer Goods and Engineering	46.1	North East Cheshire and Warrington Greater Manchester
Chemistry and Textiles	40.3	Tees Valley North East Liverpool City Region
Operations and Construction	36.9	North East Leeds City Region Lancashire

Source: PATSTAT, EPO; author's calculation

An encouraging diversity of LEPs feature in the table; most LEPs have some relative specialisations in some cross-sectional patenting activity.

5.3 Innovation Potential by LEP Area

While the overall distribution of technology classes found in patent documents across regional economies provides some interesting insights, it is really more advanced measures of variety and relatedness that offer further information about the state of available knowledge and its recombination potential at a particular place. The two most prominent technology indices in this regard are **technological entropy** and **relatedness**,[103] both of which allow not only to evaluate the present state of technological advancement in a given locality, but also offer an opportunity to project into the future in terms of the most likely technologies with the potential to add a regional competitive advantage to the local economy. A number of studies have demonstrated that there are evolutionary forces that lead to 'natural' regional economic diversification patterns, while also pointing at the possibility to use such metrics for the development of directed investments and policy instruments in order to encourage specific technological pathways with the potential to increase a regions economic performance.[104] At the level of individual LEPs, the following analysis has the potential to identify significant strengths and weaknesses in their own innovation ecosystems.

Technological Entropy

The number of available building blocks, i.e. technological classes that are present in a local economy, largely determines knowledge recombination possibilities and subsequent patterns of specialization. Measured as entropy that is comprised of unrelated and related variety, it offers an avenue to investigate the composition of specialized local technological knowledge.

As shown in Table 5.3.1**,** the Northern regions' position in terms of technological entropy scores over the 6 observed 5-year time periods in the pan-UK economy changes.

Table 5.3.1: Technological entropy scores for English LEP (and NUTS2) regions (2001-2005; 2006-2010; 2011-2015)

rank	2001-2005		2006-2010		2011-2015	
	LEP name	Entropy	LEP name	Entropy	LEP name	Entropy
1	Leeds City Region	7.44	West Wales and The Valleys	7.33	South East	7.31
2	Heart of the South West	7.38	Heart of the South West	7.30	Leeds City Region	7.24
3	Derby, Derbyshire, Nottingham and Nottinghamshire	7.27	Leeds City Region	7.23	South East Midlands	7.20
4	Stoke-on-Trent and Staffordshire	7.27	Coventry and Warwickshire	7.22	Heart of the South West	7.19
5	South East Midlands	7.21	Sheffield City Region	7.17	Lancashire	7.14
…	Lancashire (6)	7.16	Greater Manchester (7)	7.15	Cheshire and Warrington (11)	7.02
…	North East (10)	7.07	Lancashire (9)	7.13	Sheffield City Region (12)	6.97
…	Greater Manchester (16)	6.93	York, North Yorkshire and East Riding (20)	6.91	Greater Manchester (14)	6.91
…	Sheffield City Region (17)	6.90	North East (28)	6.79	North East (24)	6.77

[103] The calculation of these measures is presented in more detail in Appendix B.

[104] For a general overview see: Kogler D. F. (ed) (2016) Evolutionary Economic Geography: Theoretical and Empirical Progress. London: Routledge. For a detailed overview of Relatedness measures as a driver of economic diversification, refer to the following two publications: Boschma R. (2017) Relatedness as driver of regional diversification: a research agenda, Regional Studies, 51 (3), pp. 351-364. & Kogler, D. (2017) Relatedness as driver of regional diversification: a research agenda - a commentary, Regional Studies, 51 (3), pp. 365-369.

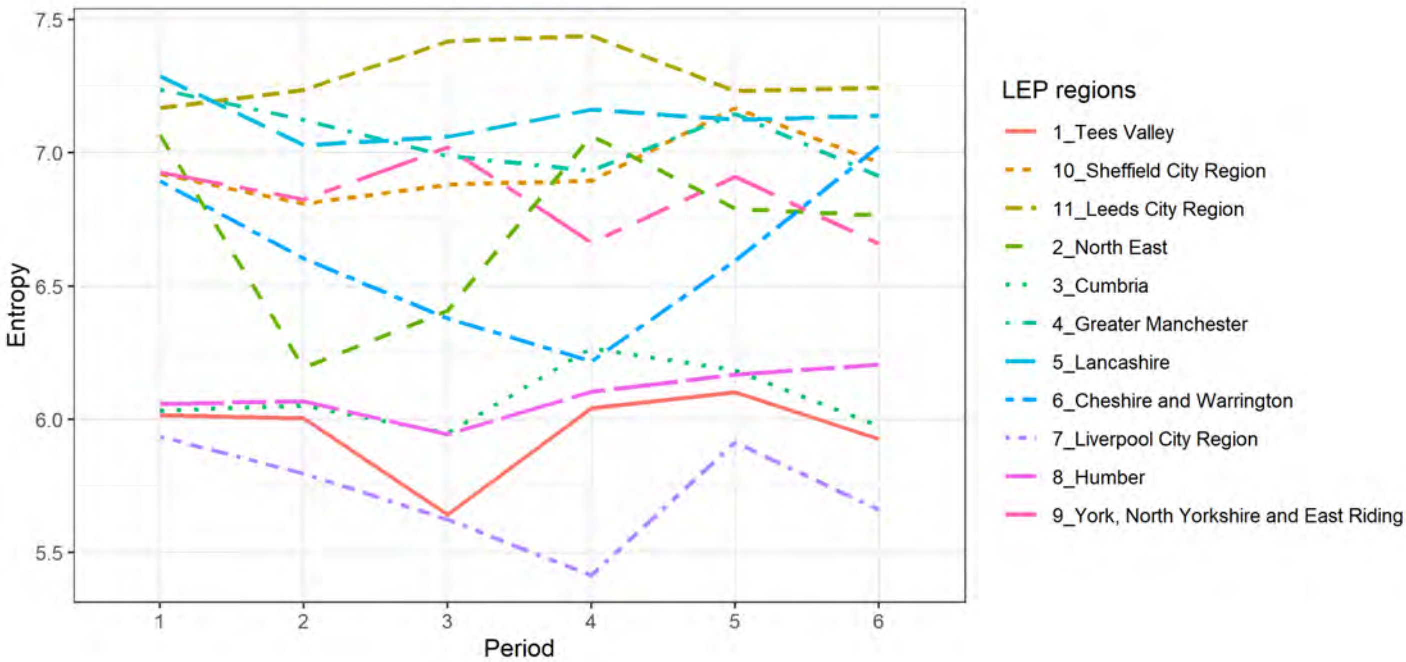
…	York, North Yorkshire and East Riding (26)	6.66	Cheshire and Warrington (29)	6.60	York, North Yorkshire and East Riding (28)	6.66
…	Cumbria (37)	6.27	Cumbria (38)	6.18	Humber (37)	6.20
…	Cheshire and Warrington (39)	6.22	Humber (40)	6.17	Cumbria (40)	5.98
…	Humber (40)	6.10	…	…	…	…
41	Tees Valley	6.04	Tees Valley	6.10	Tees Valley	5.92
42	Swindon and Wiltshire	5.93	Liverpool City Region	5.91	Liverpool City Region	5.66
43	Liverpool City Region	5.41	Greater Lincolnshire	5.53	Greater Lincolnshire	5.17
44	North Eastern Scotland	4.94	North Eastern Scotland	4.81	North Eastern Scotland	4.76
45	Highlands and Islands	4.56	Highlands and Islands	4.79	Highlands and Islands	4.21

Source: PATSTAT, EPO; author's calculation

Noticeably, Leeds City Region has been top-ranked, or at least among the top 3 ranked LEPs in almost all time periods. This indicates that Leeds City Region has a much more diverse technological knowledge base compared to its 10 LEP counterparts in the North of England, but also overall in the pan-UK space. At the same time, Liverpool City Region has been ranked close at the bottom among all UK regions over the observed 30-year period. This implies that there is a huge gap among Northern regions in terms of technological knowledge diversity, which in turn determines to a large extent the possibility to diversify into new areas of the knowledge space and to engage in advanced recombinant knowledge production.

Figure 5.3.1 presents the 11 Northern LEP regions' technological entropy scores over the six 5-year periods.

Figure 5.3.1: Changes in the 11 LEP regions' technological entropy scores



Source: PATSTAT, EPO; author's calculation

Among the 11 Northern LEP regions, Leeds City Regions and Lancashire are the leading regions in more diversified technological knowledge base. This indicates that these groups not only have a rich quantity of knowledge, but also more diversified knowledge base.

Technological Relatedness

In addition to the number of building blocks available (entropy) it is of course highly relevant to know average relatedness scores change in the Knowledge

Space. As highlighted previously, Smart Specialization is mainly about domains, i.e. technology classes, and their connectedness (relatedness), which provides a much more accurate picture of the state and possible trajectories of a regional economy. Average relatedness measures have become a key element when analysing the current and future potential of knowledge recombination activities in a given locality.

Table 5.3.2 indicates the 11 LEP regions' position in terms of regional average technological relatedness among the pan-UK economy. The Northern regions are mostly located at a ranking below 10 (out of the total number of 45 areas). While most of the Northern regions are ranked between 10 and 40, Cumbria, is ranked at the bottom. This indicates that the average relatedness score for most of the Northern regions is around the average of all English LEP regions, and there is a distinctive gap among 11 LEP regions.

Table 5.3.2: Average technological relatedness scores for English LEP (and NUTS2) regions (2001-2005; 2006-2010; 2011-2015)

rank	2001-2005		2006-2010		2011-2015	
	LEP name	AR	LEP name	AR	LEP name	AR
1	London	2.51	London	2.41	London	2.32
2	Greater Cambridgeshire and Greater Peterborough	2.40	Greater Cambridgeshire and Greater Peterborough	2.23	Oxfordshire	2.26
3	Coast to Capital	2.33	Coast to Capital	2.22	Derby, Derbyshire, Nottingham and Nottinghamshire	2.23
4	Oxfordshire	2.29	Oxfordshire	2.19	Greater Cambridgeshire and Greater Peterborough	2.21
5	Enterprise M3	2.27	Derby, Derbyshire, Nottingham and Nottinghamshire	2.16	Coast to Capital	2.16
…	Sheffield City Region (16)	2.06	Leeds City Region (15)	1.96	Leeds City Region (13)	1.88
…	Leeds City Region (18)	1.98	York, North Yorkshire and East Riding (21)	1.85	Cheshire and Warrington (15)	1.82
…	Cheshire and Warrington (22)	1.94	Cheshire and Warrington (22)	1.83	Lancashire (23)	1.67
…	York, North Yorkshire and East Riding (23)	1.88	Greater Manchester (24)	1.80	Liverpool City Region (24)	1.66
…	Greater Manchester (26)	1.78	Sheffield City Region (27)	1.72	York, North Yorkshire and East Riding (26)	1.60
…	Liverpool City Region (29)	1.70	Tees Valley (30)	1.67	Greater Manchester (31)	1.51
…	North East (32)	1.66	Liverpool City Region (31)	1.63	Sheffield City Region (32)	1.49
…	Tees Valley (34)	1.62	Lancashire (34)	1.53	Humber (36)	1.34
…	Humber (35)	1.60	Humber (35)	1.51	North East (37)	1.32
	Lancashire (38)	1.56	North East (40)	1.40	Tees Valley (40)	1.25
41	Greater Lincolnshire	1.18	North Eastern Scotland	1.35	The Marches	1.07
42	The Marches	1.17	Black Country	1.27	North Eastern Scotland	1.06
43	Cornwall and Isles of Scilly	1.11	Cornwall and Isles of Scilly	1.24	Highlands and Islands	1.04
44	Highlands and Islands	1.09	Cumbria	1.20	Black Country	0.94
45	Cumbria	0.88	Highlands and Islands	1.15	Cumbria	0.93

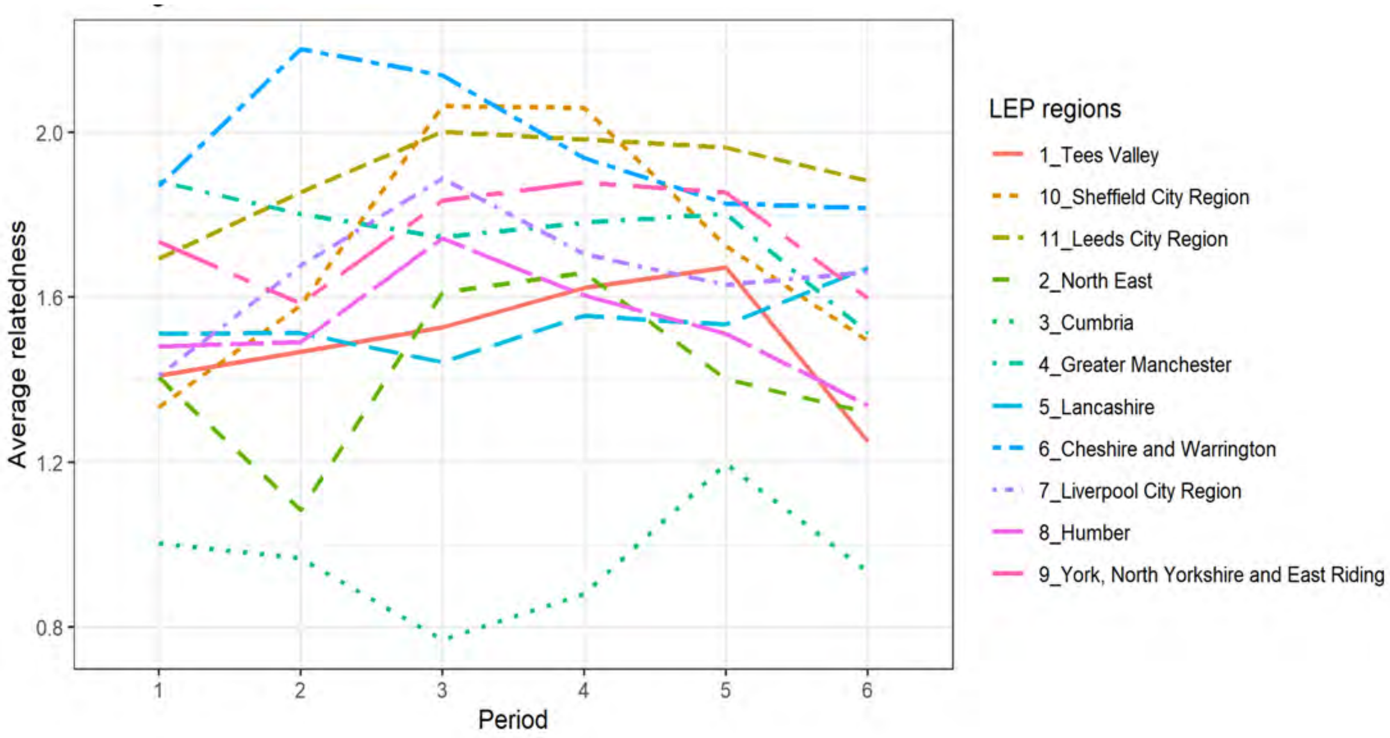
Source: PATSTAT, EPO; author's calculation

Figure 5.3.2 shows the LEP regions' average technological relatedness score. While a high average relatedness score doesn't necessarily directly translate into economic success, it has previously been demonstrated that higher relatedness scores also result in an increase of the rate of patenting.[105] In the

[105] Kogler D. F., Rigby, D. L. and Tucker, I. (2013) Mapping knowledge space and technological relatedness in US cities. European Planning Studies, 21: 1374–1391.

earliest time period, 1986-1990, Cheshire and Warrington had the highest average technological relatedness, but its rank has been fallen. On the other hand, the high level of average technological relatedness has remained for Liverpool City Region and Leeds City region. This indicates that the average connectedness of individual knowledge domains in these two regions has remained stable while Cheshire and Warrington have not. Moreover, the score of the lower group (Cumbria, Lancashire, and Greater Manchester) has been increased. It implies the possibility that these regions participate in more patenting activity, which may narrow down the gap between regions in the following period.

Figure 5.3.2: The 11 LEPs regional average technological relatedness score changes over a 30-year period



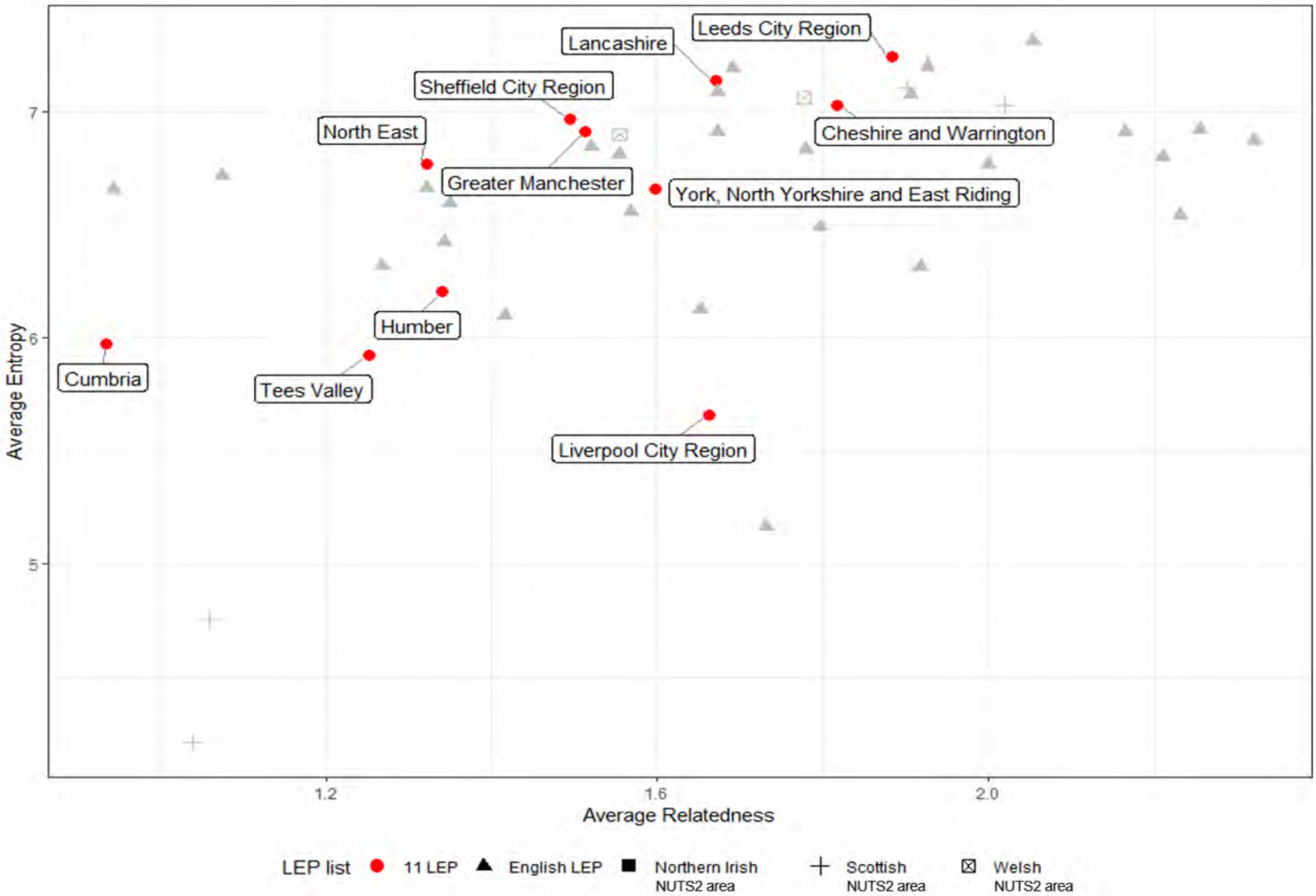
Source: PATSTAT, EPO; author's calculation

Recombinant Knowledge Production

It is possible to put the two measures of entropy and average relatedness into one framework, and subsequently test for the ability of a region to produce novel recombinant knowledge. Combining nodes, i.e. technology classes, that have been previously unconnected and subsequently developing a competitive advantage (LQ > 1) in new recombinant knowledge serves as an indicator of the technological knowledge production capabilities residing in a jurisdiction. The expectation is that a higher value of entropy, which refers to the number and distribution of classes, paired with a high value of average relatedness, which indicates that nodes exhibit a certain level of proximity to each other in the knowledge space, should also lead to more recombinant knowledge to be produced in a place.

Figure 5.3.3 Illustrates the number of new recombinant knowledge in the North in 2011-2015. The size of the nodes indicates the number of unique CPC used in each region. Further, on the two axes of the graph the level of average relatedness and entropy that are present at individual regions is highlighted. Leeds City Region, located at the top right-hand corner, is characterized by a high entropy and relatedness value, but also a very high number of CPCs used for new recombinant knowledge production. This indicates Leeds City Region is top leading region in the recombinant knowledge production among the Northern LEP regions. In 2011-2015, the gap between regions are narrowed down relative to the previous period.

Figure 5.3.3: New recombinant knowledge production at regional scale (2011-2015)



Source: PATSTAT, EPO; author's calculation

LEPs may wish to consider strategies of encouraging either innovation diversification or specialisation, depending upon their location in Figure 5.3.3. They may also wish to consider the extent to which they are either under- or over- performing in the production of patents, relative to their recombination knowledge production potential as identified above, and why this might be.

In order to understand this, it is useful for LEPs to understand their area's own existing specialisations. The specialisations of individual Northern LEPs are shown in appendix A. Here we show both the top 20 patents by absolute figures, and the location quotient – that is, the extent to which LEPs have a relative speciality in a technology compared to the national average.

5.4 The role of industrial sectors in patenting activity

In order to further explore the relationship between employment specialisation and patenting activity at the LEP level, patent location quotients by technology were converted to location quotients by industry. This conversion was largely based on the 2015 Eurostat technology-industry concordance table,[106] which updated the table developed by Schmoch et al. (2003).[107] The table allocates 4-character IPC technology codes to the 2-digit NACE codes. NACE is the Statistical classification of economic activities in the European Community, and is equivalent to the UK Standard Industrial Classification (SIC) “down to and including the four digit class level”.[108] It should be noted that the Eurostat concordance table maps technologies almost exclusively to manufacturing sectors.

As mentioned in Section 0, the EPO patent data follow the CPC system, which is almost identical to the IPC system. A more important complicating factor is that the data are available at the 3-character rather than the 4-character level. The implication is that a direct one-to-one correspondence between the 3-character CPC technologies and the 2-digit SIC codes could not be established for all technologies. For this reason, the number of patents for each technology were more than one matches existed was split between the two most prevalent industries.

In order to generate a technological industry sector profile for the UK it is necessary to translate CPC classes into industry sectors. One advanced approach to achieve this task is to utilize a concordance table based on an algorithmic link with probabilities that matches patent with industry sector data.[109]

Based on the process described above, Figure 5.4.1 plots a sector breakdown of employment (y axis) against patents (y sector). Employment figures for 2015 were sourced from BRES. The group of sectors circled in red are the ones that the evidence suggests typically produce the highest levels of patenting activity per employee. These are:

- Pharmaceuticals
- Beverages
- Tobacco
- Electrical equipment
- Other manufacturing
- Chemicals

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[106] Van Looy, B., Vereyen, C., & Schmoch, U. (2015). *Patent Statistics: Concordance IPC V8 – NACE REV.2 (version 2.0).* https://ec.europa.eu/eurostat/ramon/documents/IPC_NACE2_Version2_0_20150630.pdf

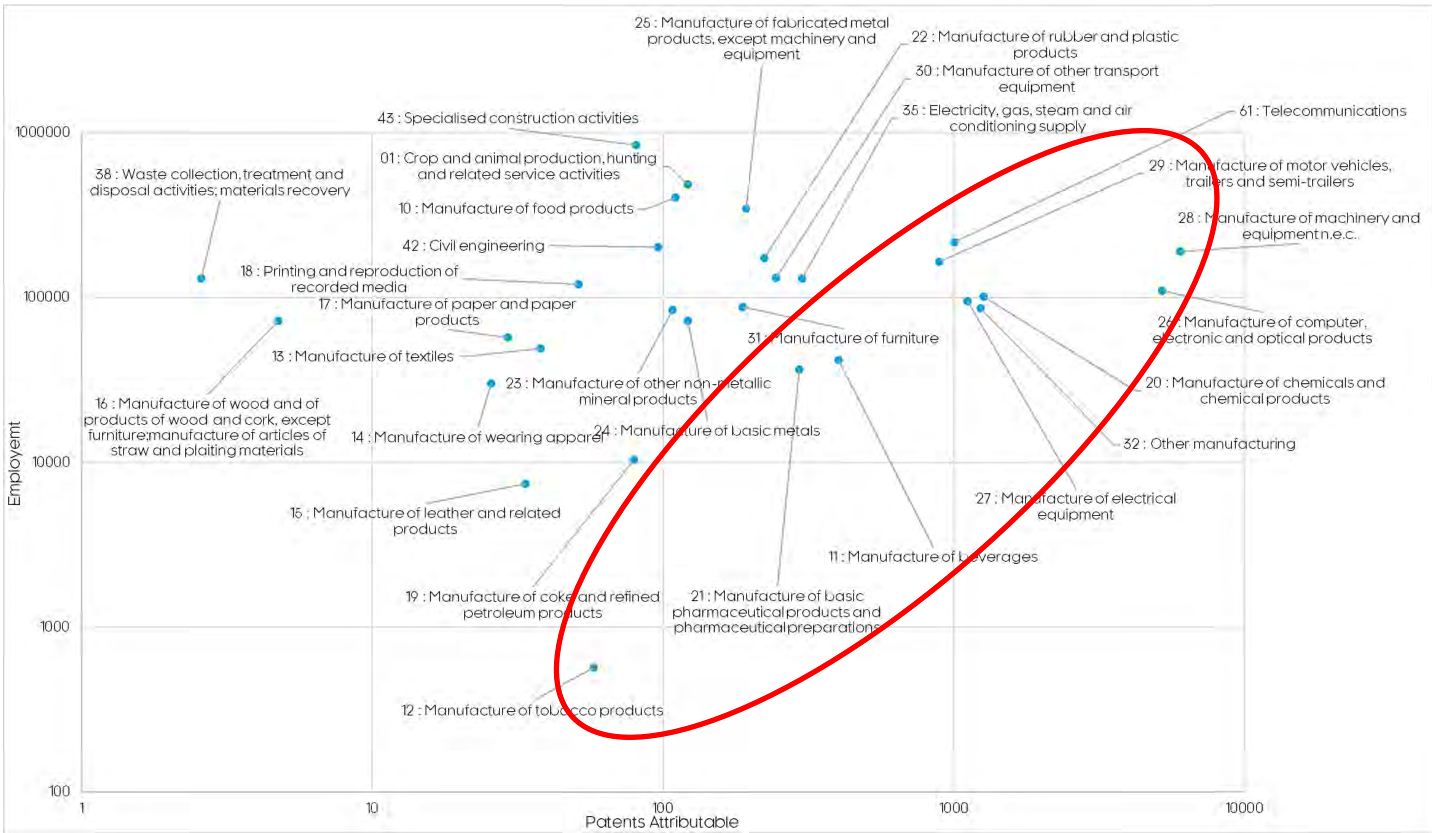
[107] Schmoch, U., Laville, F., Patel, P., & Frietsch, R. (2003). Linking technology areas to industrial sectors. Final Report to the European Commission, DG Research. https://pdfs.semanticscholar.org/ba68/b230ba1541fb3e5571bc9fb53e698ab5b7de.pdf

[108] ONS (2009). *UK Standard Industrial Classification of Economic Activities 2007 (SIC 2007). Structure and explanatory notes.* https://www.ons.gov.uk/file?uri=/methodology/classificationsandstandards/ukstandardindustrialclassificationofeconomicactivities/uksic2007/uksic2007web.pdf

[109] Lybbert, T. J., and Zolas, N. J. (2014). Getting patents and economic data to speak to each other: An ‘algorithmic links with probabilities’ approach for joint analyses of patenting and economic activity. Research Policy, 43(3), 530-542.

- Machinery
- Motor vehicles
- Computers and electronics
- Telecommunications

Figure 5.4.1: Patents and employment by sector in Great Britain



Source: EPO, PATSTAT; BRES; author's calculations

One of the outcomes of the work performed by Schmoch et al.(2003) and Van Looy et al. (2015) in creating a patent-industry translation table was the identification of an extremely a strong correlation between patenting activity and all forms of manufacturing; this is the reason why almost every sector shown on the figure above is a manufacturing section. This itself is an important insight for a historic manufacturing stronghold such as the North (this also applies to the Midlands, although the Midlands has different manufacturing specialities). The manufacturing sector is not only a key provider of exports and high-quality jobs, but evidence suggests that it also has a key role to play in any innovation ecosystem.

Northern Technological Industry Profile

Following this methodology, each of the Northern LEP Knowledge Spaces were translated into technological industry profiles for the 6 time periods, respectively.

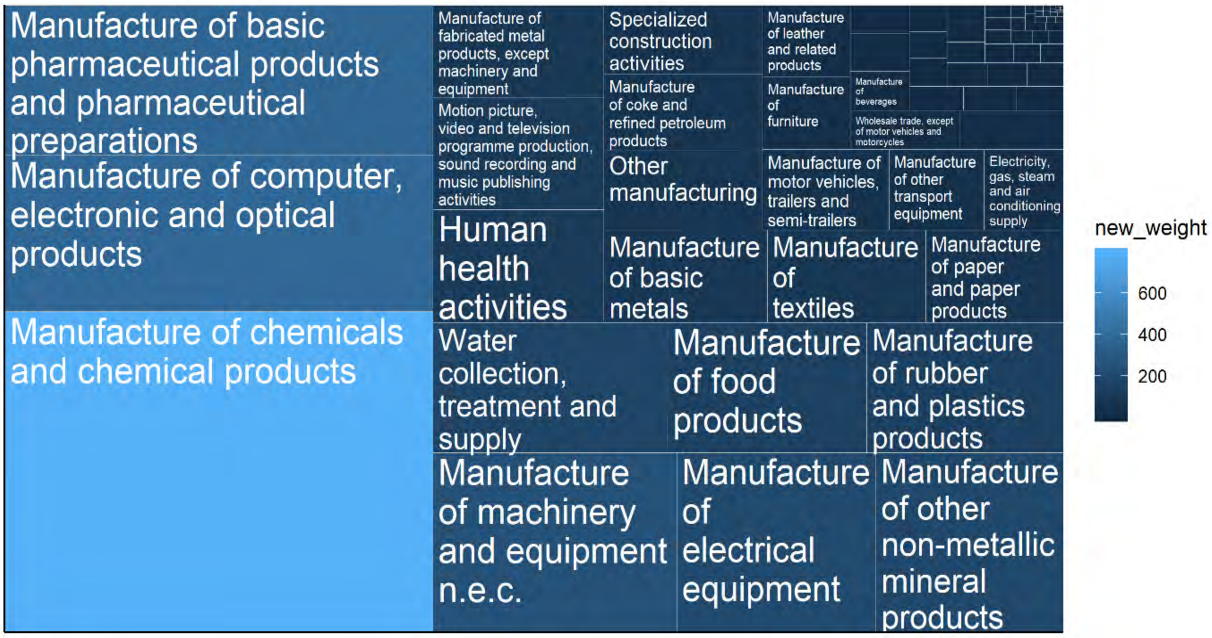
In the period 2011-2015, this distribution of industry sectors has slightly changed reflecting the shifting patterns of knowledge production in the country. While the manufacturing of chemicals and chemical and the manufacturing of basic pharmaceutical products and pharmaceutical preparations remains the top technology industry sector, the rank of the manufacturing of computer, electronic and optical products, and electrical equipment have been raised. Notable, the industry sector that relates to the human health activities is one of the new entrants in the list of top 10 technology related industry sectors in 11 LEP, 2011-2015 as listed in Table 5.4.1, below. Again, Figure 5.4.2 shows a graphic overview of the sectorial distribution in the format of a TreeMap chart.

Table 5.4.1: Top 10 technology related industry sectors in 11 LEP, 2011-2015

Top 10 Industry	Weight
Manufacture of chemicals and chemical products	793.2
Manufacture of computer, electronic and optical products	386.5
Manufacture of basic pharmaceutical products and pharmaceutical preparations	370.1
Manufacture of machinery and equipment n.e.c.	253.4
Manufacture of electrical equipment	206.8
Manufacture of other non-metallic mineral products	194.7
Water collection, treatment and supply	176.1
Manufacture of food products	149.5
Manufacture of rubber and plastics products	147.7
Human health activities	111.5

Source: PATSTAT, EPO; author's calculation

Figure 5.4.2: Technological industry sector profile for Northern regions, 2011-2015



Source: PATSTAT, EPO; author's calculation

Translating technology classes into their application across industry sectors is of particular interest in terms of a) taking stock of what industry sectors produce and exploit technological knowledge, and b) when the aim is to develop more informed smart specialization strategies that either aim to support existing capabilities or have the objective to foster the further establishment of industry sectors that are currently underrepresented based on the technological profile of a region or nation. Based on the results derived and displayed in Table 5.4.1, but without actually knowing the real distribution of industrial sectors in 11 LEP, it is challenging to make specific recommendations, but it appears that sectors that manufacture chemical and pharmaceutical products, electric and computer devices as well as human health activities are critical elements of the knowledge production system. When benchmarked to the actual distribution of industry sectors in the country, i.e. the full set of sectors rather than just those linked to technical knowledge production, policy intervention then should be geared either to supporting those sectors, or to develop strategies to increase the share of such sectors in the national economy as they would find an innovative environment that would allow them to gain a competitive advantage over firms that are located in localities where the specialized knowledge that is essential for these particular sectors is not available.

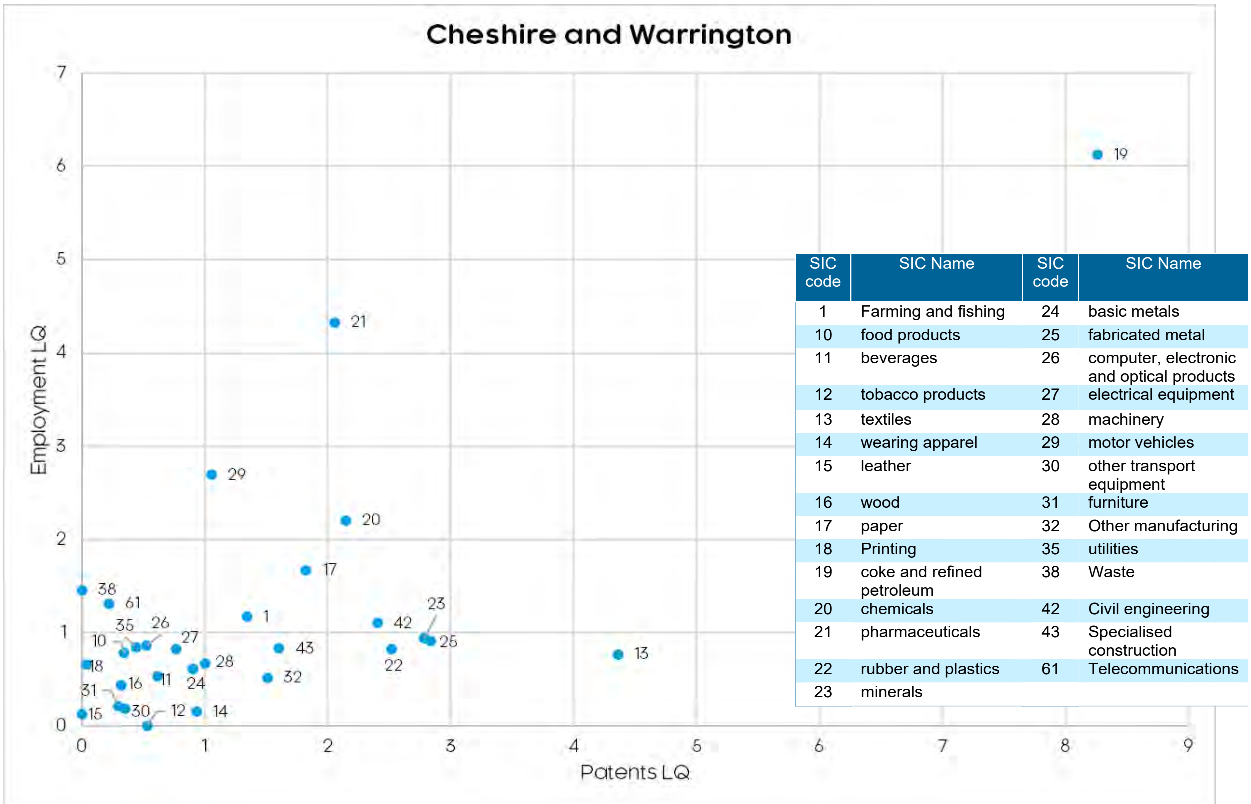
LEP level results – LQs of sectors vs LQs of technologies

The charts below show the relationship between the industrial sectors that local patenting activity is attributable to, based on the technology-sector conversion matrix, vs the actual level of employment in that sector for two selected LEPs,[110] Cheshire & Warrington and Lancashire. Both have been converted to location quotients; so what is being contrasted here are relative local specialisations in employment vs patenting for different local sectors.

- Cheshire & Warrington has eight industrial sectors that produce patents at a rate twice that of the national average. The obvious standout is the coke and petroleum industry, that is the most specialised sector in the LEP in both employment and patenting activity. The textiles sector relatively “overperforms” with a high ratio of patents/worker, whereas the pharmaceuticals sector relatively underperforms on this measure, with a low patents/worker ratio.
- Lancashire has nine industrial sectors that produce patents at a rate twice that of the national average, including textiles, leather and wearing apparel, rubber & plastics, and specialised construction. Sectors with a high patents/workers ratio include waste remediation and minerals, whereas other transport equipment, although a strong performer in general for the LEP, has a relatively low patents/worker ratio.

[110] The charts for all Northern LEPs can be found in Appendix C5.

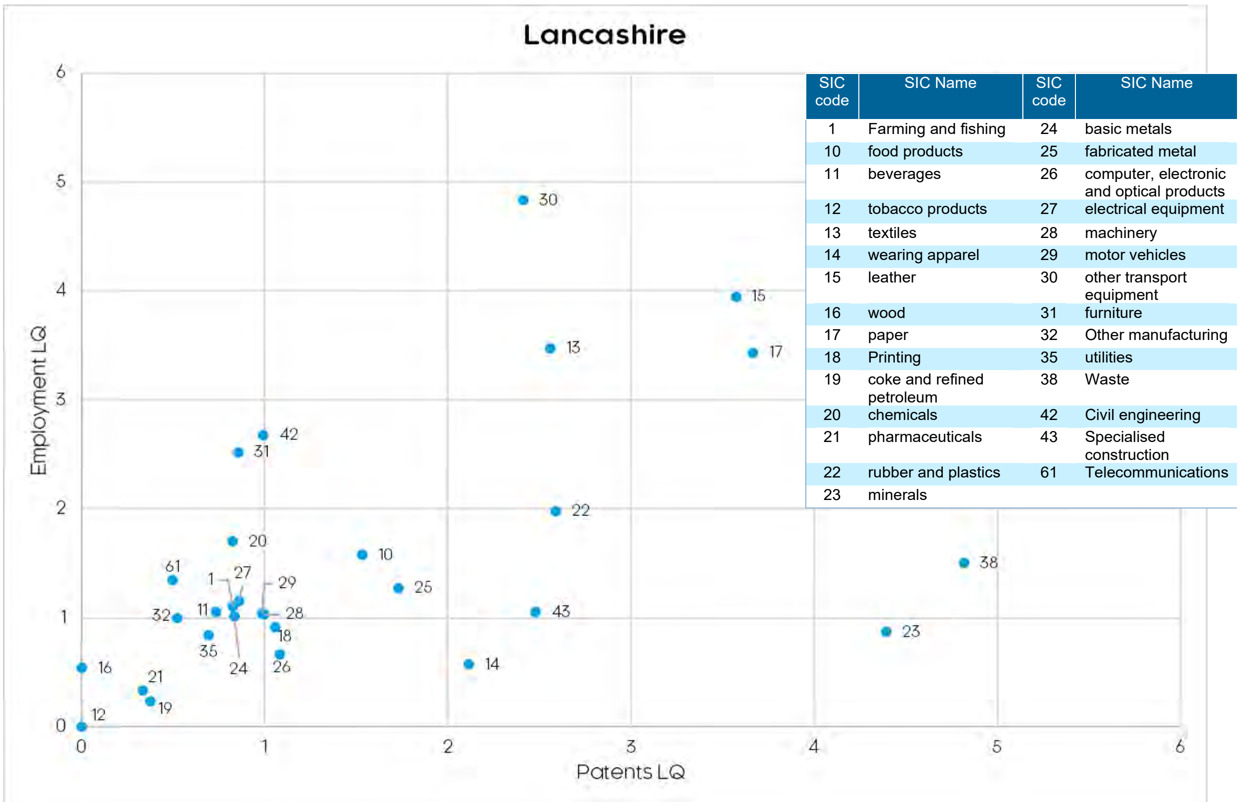
Figure 5.4.3: Employment and patent LQs, Cheshire and Warrington



SIC code	SIC Name	SIC code	SIC Name
1	Farming and fishing	24	basic metals
10	food products	25	fabricated metal
11	beverages	26	computer, electronic and optical products
12	tobacco products	27	electrical equipment
13	textiles	28	machinery
14	wearing apparel	29	motor vehicles
15	leather	30	other transport equipment
16	wood	31	furniture
17	paper	32	Other manufacturing
18	Printing	35	utilities
19	coke and refined petroleum	38	Waste
20	chemicals	42	Civil engineering
21	pharmaceuticals	43	Specialised construction
22	rubber and plastics	61	Telecommunications
23	minerals		

Source: EPO, PATSTAT; BRES; author's calculations

Figure 5.4.2: Employment and patent LQs, Lancashire



SIC code	SIC Name	SIC code	SIC Name
1	Farming and fishing	24	basic metals
10	food products	25	fabricated metal
11	beverages	26	computer, electronic and optical products
12	tobacco products	27	electrical equipment
13	textiles	28	machinery
14	wearing apparel	29	motor vehicles
15	leather	30	other transport equipment
16	wood	31	furniture
17	paper	32	Other manufacturing
18	Printing	35	utilities
19	coke and refined petroleum	38	Waste
20	chemicals	42	Civil engineering
21	pharmaceuticals	43	Specialised construction
22	rubber and plastics	61	Telecommunications
23	minerals		

Source: EPO, PATSTAT; BRES; author's calculations

6 Innovation Collaboration Networks

Introduction

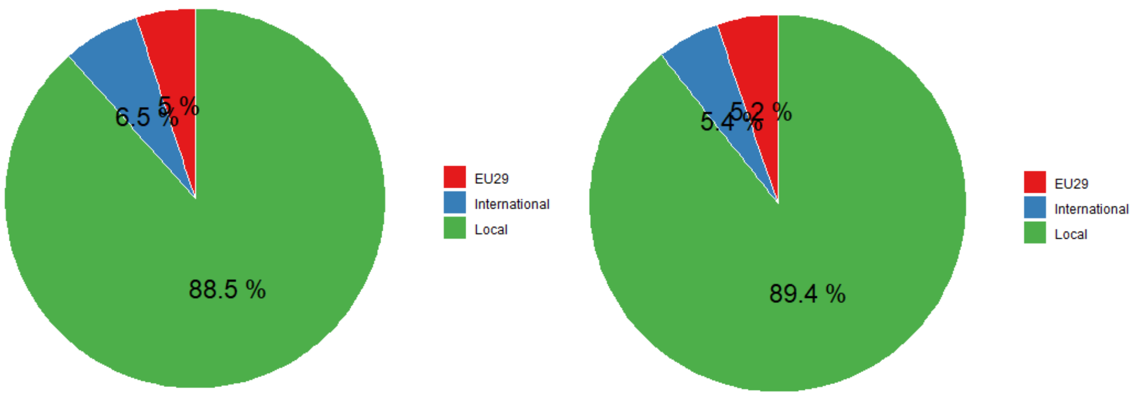
The innovation logic map derived in chapter 2 of this report identified the role of collaboration across networks of different scales as a key driver in every stage of innovation activity, from the initial stages of knowledge generation and value creation, to the dissemination and adoption of new ideas, methods and technologies. This chapter uses a combination of patent co-invention records and Innovate UK funding applications to investigate the spatial patterns of innovation collaboration across the UK.

6.1 Patent Co-Inventions

Most patented inventions are produced in collaboration. Inventor collaborations are usually highly localized, i.e. inventor teams are usually co-located in space while working on the development of a novel product or process. However, even if non-local collaborations are more infrequent, they do serve as an important conduit for accessing extra-local knowledge resulting in knowledge spillovers that might compensate for relevant expertise in the development of an invention that is not available locally.

Figure 6.1.1 illustrates this and shows that over the whole 1986-2015 timeframe, of all patents that that had at least one inventor resident in the North, 89% of listed inventors resided in the UK at the time of invention, with 11% residing outside the UK. Here, we differentiate European countries (EU29) and other non-European countries (international). [111]

Figure 6.1.1: Share of UK (local) and non-UK (EU29/International) inventors listed on UK patents (left) as well as the same distribution for only patents that contain at least one inventor residing in the study area (1986-2015).



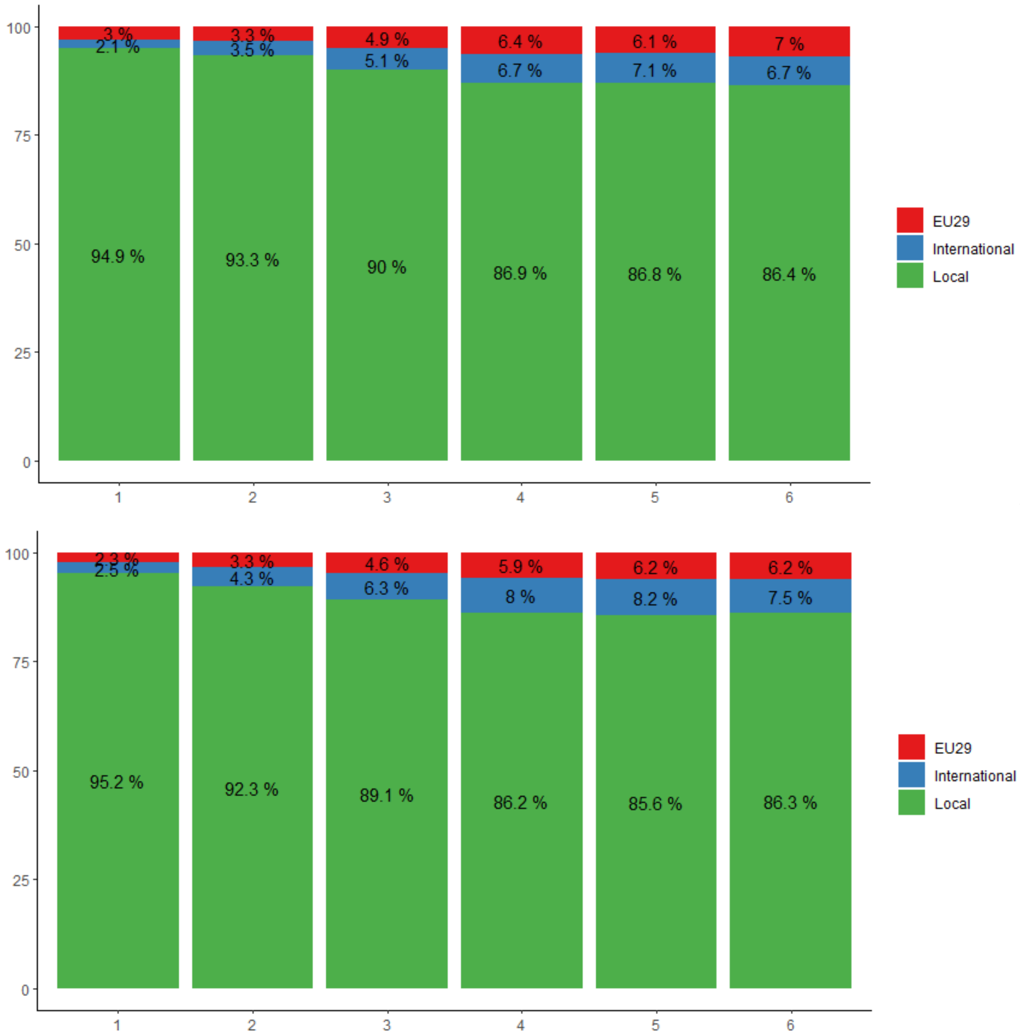
Source: PATSTAT, EPO; author's calculation

The share of international inventor collaborations over the observed timeframe is further elaborated in Figure 6.1.2. Looking at the trend over 30-year period (1986-2015) the share of patents that have been developed in collaboration between UK and foreign inventors has increased substantially. There is no

[111] EU27+2, subsequently referred to as "EU29" includes AT, BE, BG, CZ, CY, DK, DE, EE, ES, FI, FR, GR, HU, HR, IE, IT, LV, LT, LU, MT, NL, PL, PT, RO, SI, SK, SE and CH & NO.

significant difference between filings containing a North-resident inventor and those without.

Figure 6.1.2: National, EU29 and International inventor collaboration (top: all UK regions; bottom: 11 LEPs)

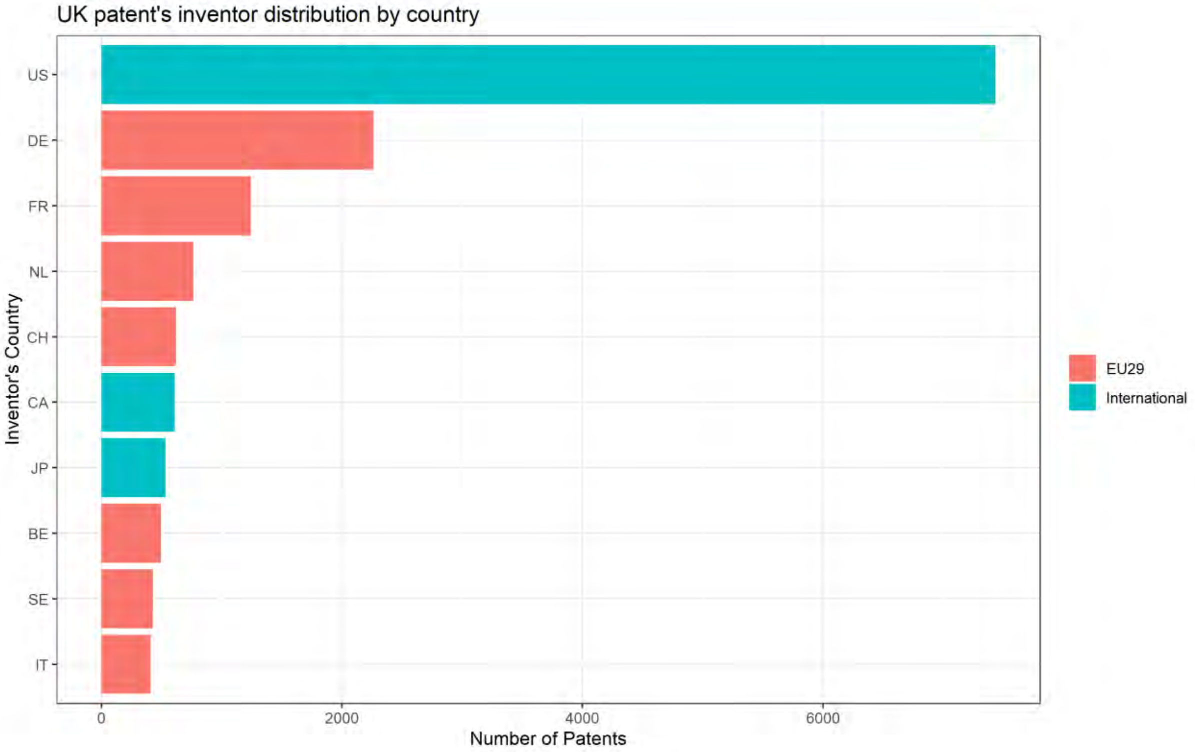


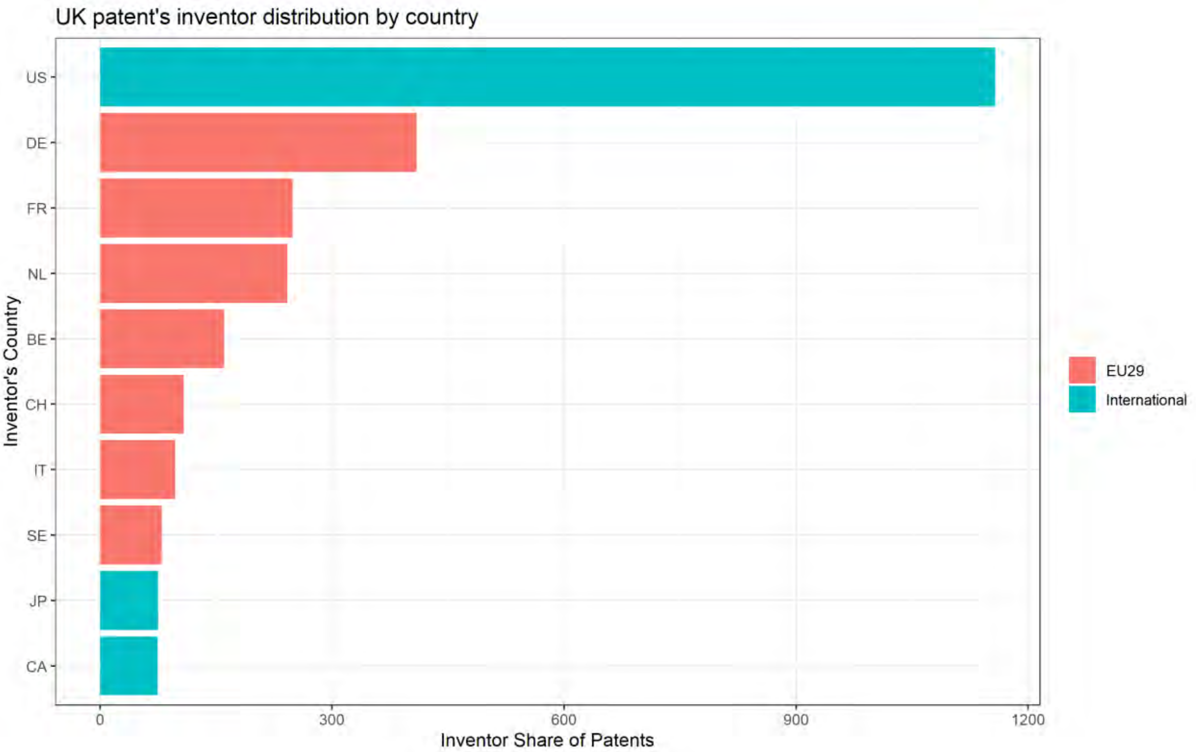
Source: PATSTAT, EPO; author's calculation

In terms of the origin of EU29 and international co-inventors, Figure 6.1.3 provides a further breakdown. The vast majority of international collaborations of UK inventors are with inventors located in the United States. Among top 10 countries, 7 countries are EU29. Among co-inventors resident in European countries, those located in Germany, France and the Netherlands feature most prominently; both for all UK inventors (top of figure) as well as those co-invented with 11 LEP resident inventors (bottom of figure).

Compared to the wider UK, inventors from the North collaborate relatively more frequently with inventors based in Germany, France, Belgium and the Netherlands. The above data show that inventors from the North are as likely to collaborate internationally as inventors elsewhere in the country. They are however marginally more likely to collaborate with EU-based partners.

Figure 6.1.3: Share of top 10 non-UK (EU29/International) inventors listed on patents that contain at least one UK inventor (top) and one inventor from the North of England (bottom)





Source: PATSTAT, EPO; author’s calculation

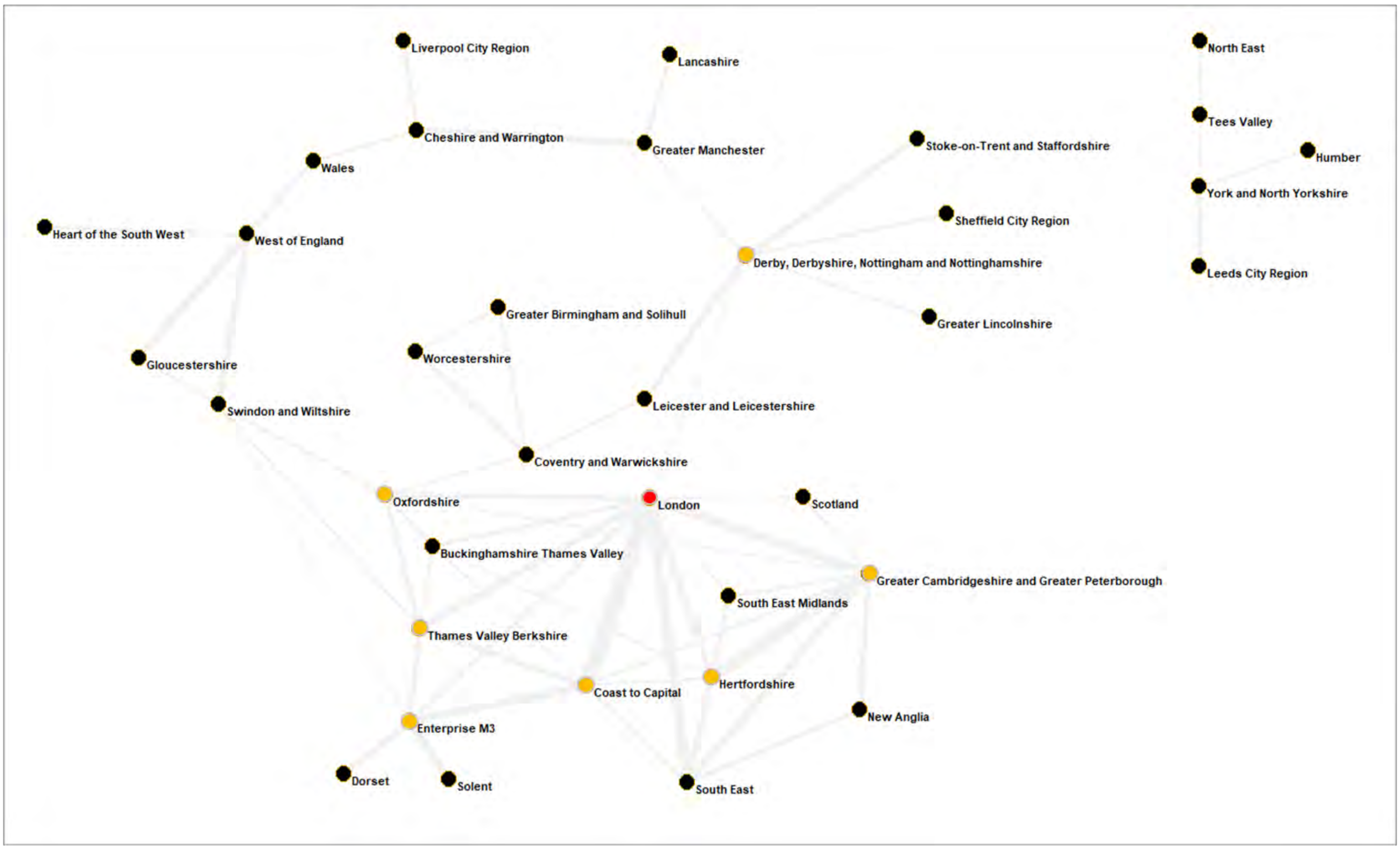
Inter-LEP collaboration patterns

As well as investigating the prevalence of international collaborations, the patent data allowed us to investigate the pattern of collaboration data within the UK, in particular between inventors based in different LEPs. The three nations of the UK, Scotland, Wales and Northern Ireland were also included in the analysis as individual entities.

Figure 6.1.4 shows a network graph depiction of the co-invention relationship between different English LEP regions, Scotland and Wales in the period 2001-2015. In order to generate this graph, a matrix of LEP region -LEP region co-invention occurrences was constructed based on the location residence of each listed inventor on the patent filing.

In order to generate a clear and coherent network graph, a cut-off was introduced at 50 co-inventions over the 14-year period. Connections above this threshold are shown with an edge on the graph below, with stronger connections above this threshold showing as thicker lines; LEPs with 6 or above connections are shown with nodes marked in yellow, and 10 or above in red. The exact location of nodes are not quantitatively significant; they are arranged to allow maximum visual clarity as to the pattern of connections.

Figure 6.1.4: Network graph of patent co-inventions



Source: EPO, PATSTAT; author's calculations

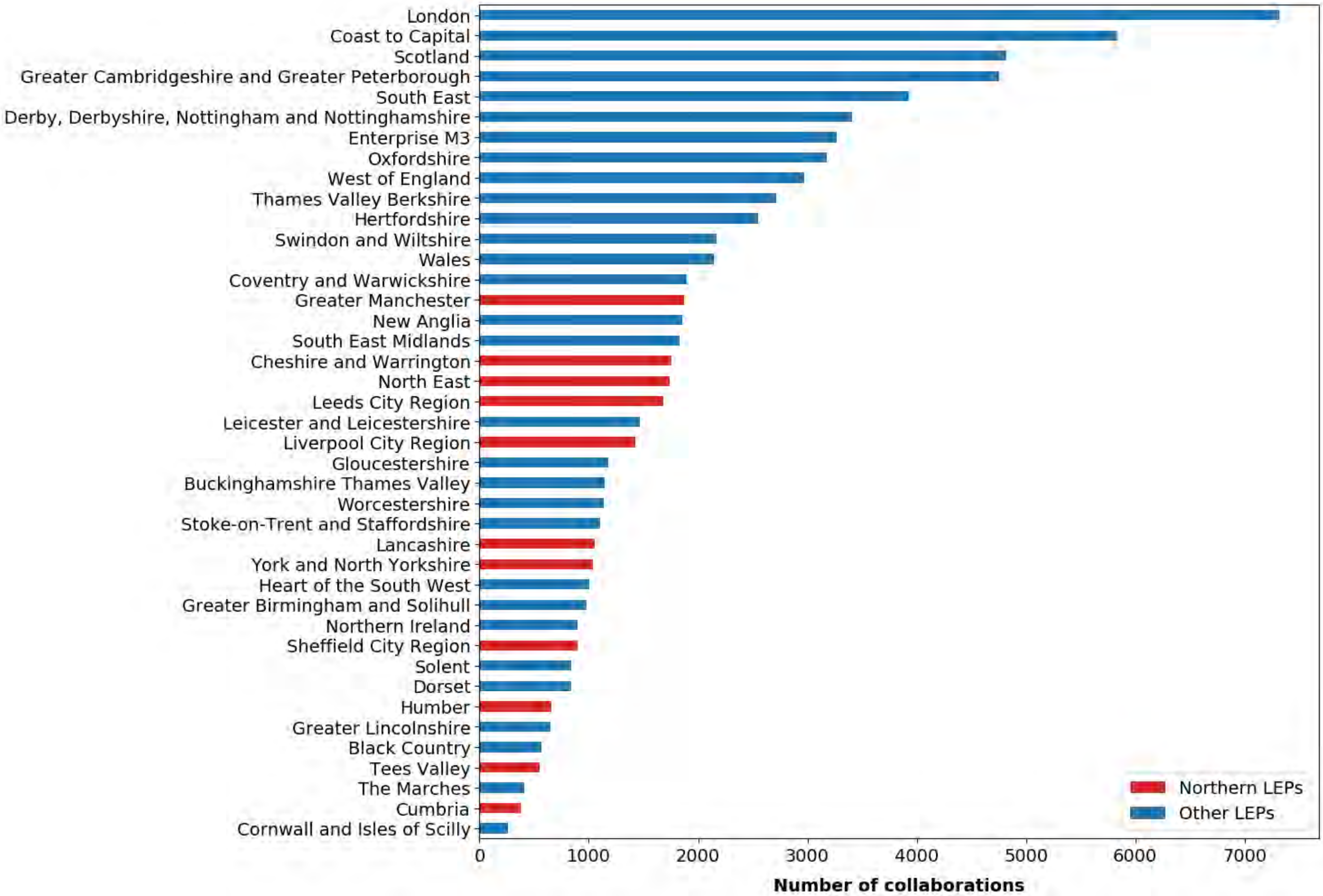
The results of this exercise are striking. The network naturally divides into three parts:

- A densely interconnected sub-network shown to the bottom of the diagram. This contains one node with 10+ connections (London) and six further nodes with 6+ connections (Oxfordshire, Thames Valley Berkshire, Enterprise M3, Coast to Capital, Hertfordshire, and Greater

Cambridgeshire and Greater Peterborough). Notably, with the exception of Scotland, which has links to London and GCGP, all other nodes within this sub-network are located within the Greater South East.

- A geographically defined ring network covering the West of England, Wales, the North West, and the Midlands. Each node tends to have connections only to its geographic neighbours or near neighbours. Of the nodes in this sub-network, only Derby, Derbyshire, Nottingham and Nottinghamshire has connections to 6 or more other nodes.
- A separate smaller network of 5 nodes covering Yorkshire and the Humber and North East England, that has no significant connection to the main network.

Figure 6.1.5: Total patent co-inventions by LEP region (2001-15)



Source: EPO, PATSTAT; author's calculations

These spatial networks suggest that the North and Midlands innovation ecosystems are less dense, and therefore less developed, than those located in the South (particularly South East), reflecting lower levels of collaboration and networking, and to a lesser extent, physical connectivity. High levels of collaboration between neighbouring LEPs may reflect the probability towards cross-LEP commuting movements. Knowledge that is being generated in the North is therefore unlikely to be shared as widely or efficiently within its innovation ecosystem, whilst external knowledge that enters the North is less likely to permeate widely into the network.

Figure 6.1.5 (above) confirms this: ignoring for a moment the other nations of the UK, 9 of the top 10 LEPs in this figure are based in the greater South East, with only D2N2 featuring in the top 10. Northern LEP regions, like Midland LEP regions, tend to appear roughly halfway down the table.

Table 6.1.1 shows the within-North connections of the 11 LEP regions comprising that region, including within-LEP region collaborations. As the connections are symmetric, only the top-right half of the matrix is filled in. Two observations are noticeable:

- Firstly, the highest levels of collaborations are between inventors within the same LEP region; this is quite likely reflecting the propensity for co-inventors to work within the same organisation.
- Secondly, there is a large degree of sub-regionality within these patterns; for example, of other Northern LEP regions, co-inventors in Liverpool City Region are most likely to collaborate with co-inventors in directly neighbouring LEPs of Cheshire & Warrington, Greater Manchester and Lancashire, with limited interaction elsewhere, with the possible exception of Leeds City Region.

Table 6.1.1: Patent co-inventions among LEPs in the North of England (2001-15)

	Cumbria	Cheshire and Warrington	Greater Manchester	Humber	Lancashire	Liverpool City Region	Leeds City Region	North East	Sheffield City Region	Tees Valley	York, and North Yorkshire
Cumbria	268	1	5	1	27	1	9	4	1	1	2
Cheshire & Warrington		976	185	7	43	101	7	13	5	1	6
Greater Manchester			1148	2	106	43	37	10	15	2	6
Humber				385	2	2	25	1	10	2	60
Lancashire					638	46	26	12	3	12	17
Liverpool City Region						1015	21	2	2	4	3
Leeds City Region							1167	24	39	2	117
North East								1347	18	80	46
Sheffield City Region									514	4	26
Tees Valley										251	84
York & North Yorkshire											545

Source: EPO, PATSTAT; author's calculations

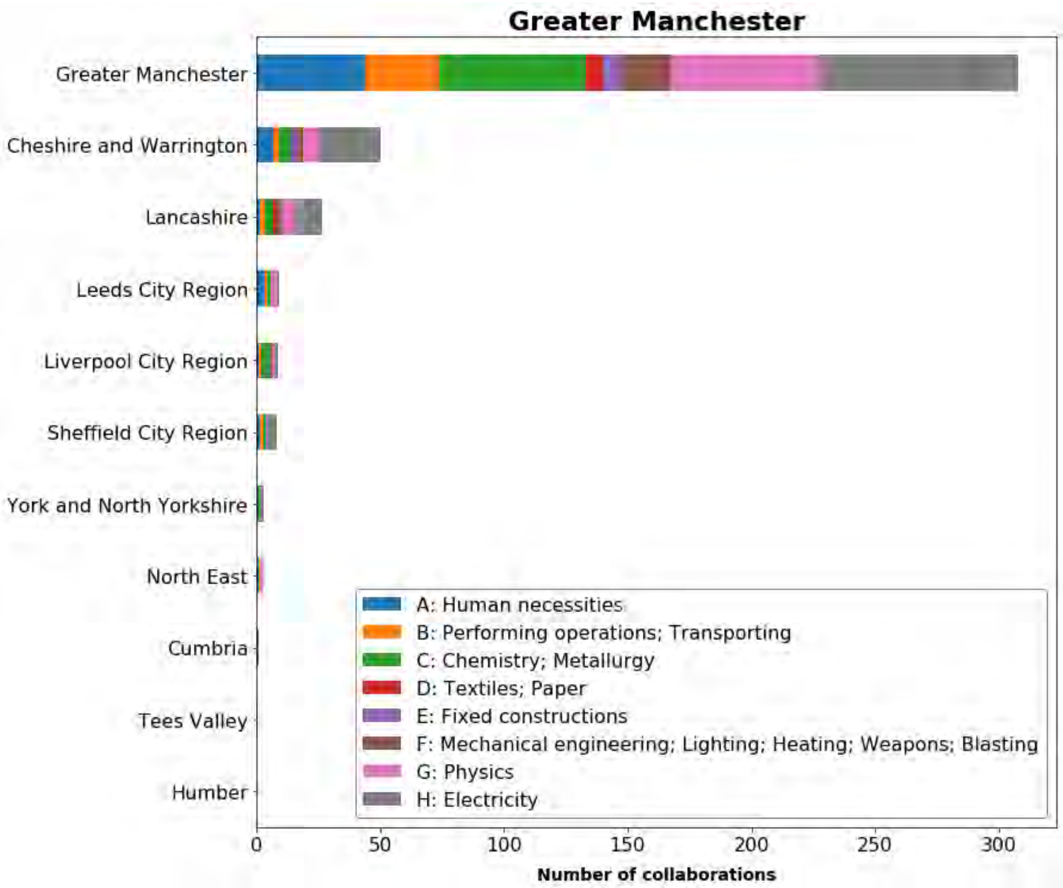
Patent collaborations by technology

When looking at collaboration patterns within the North, an obvious next question is to ask how this varies by technology.

Fortunately, we are also able to identify which technologies each pair of LEPs are collaborating in. The following charts shows a breakdown of leading partners by technology for each of the 11 Northern LEPs can be found in Appendix D1. Two examples are shown here:

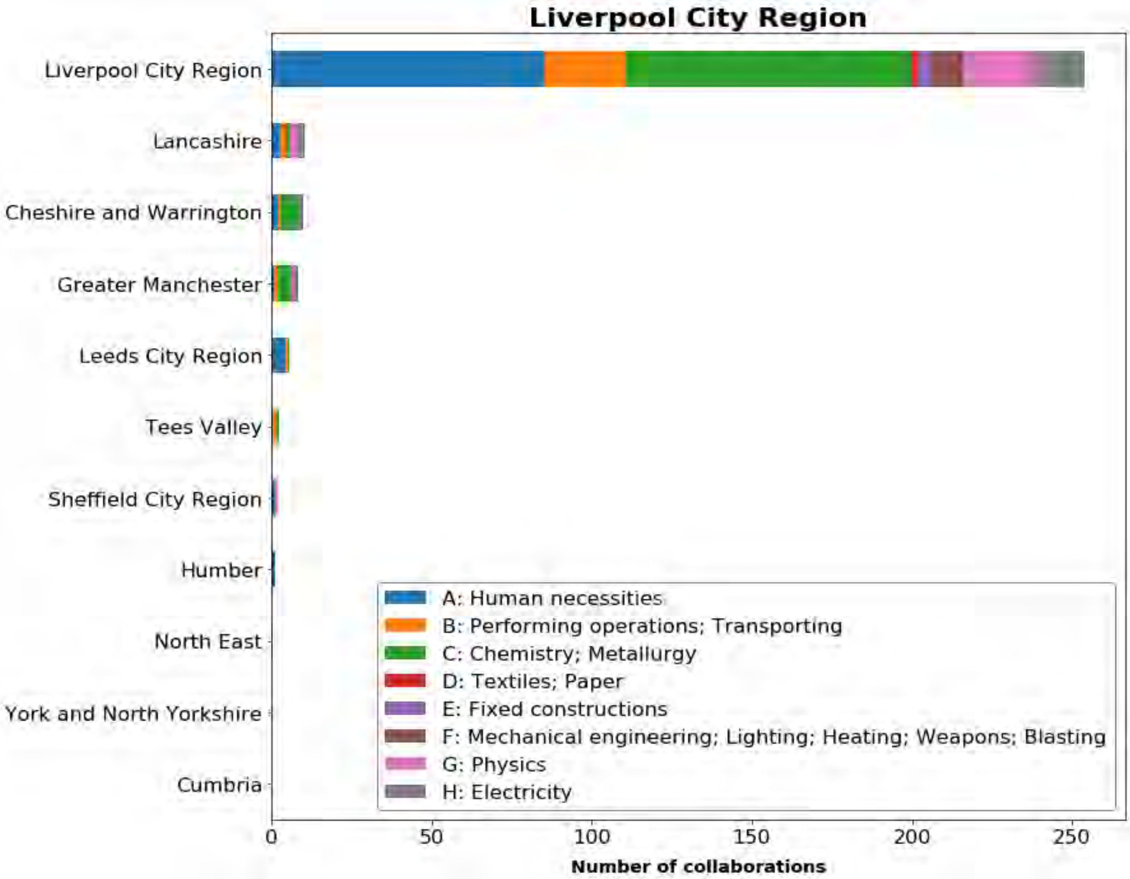
- **Greater Manchester** has the highest number of collaborations of all Northern LEPs. Within-LEP collaborations feature human necessities, chemistry, physics and electricity, and electricity is prominent in collaborations with Cheshire & Warrington, Lancashire and Sheffield. We also see collaborations with Leeds on human necessities, and Liverpool on Chemistry.
- **Liverpool City Region's** within-LEP collaborations are primarily based around Human Necessities and Chemistry. Cross-LEP collaborations are relatively low by comparison. Collaborations with Cheshire & Warrington are strongly dominated by Chemistry sub-classes.

Figure 6.1.6: Patent co-inventions by broad technology, Greater Manchester



Source: EPO, PATSTAT; author's calculations

Figure 6.1.7: Patent co-inventions by broad technology, Liverpool City Region

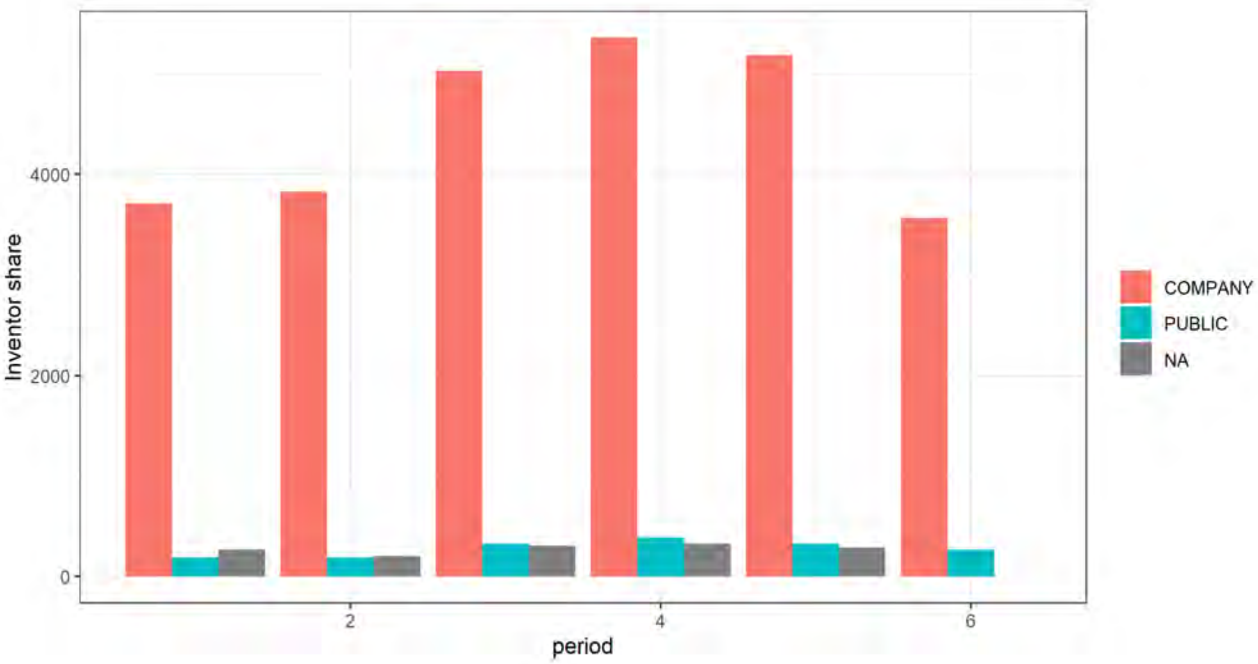


Source: EPO, PATSTAT; author's calculations

Knowledge Producing Entities in the North

A further question is with regard to the types of organisation partaking in patenting activity and collaborative activity. Taking the sample of patents described and analysed in the previous section, attention now shifts to the entities that are associated with those patents. Commonly, these are referred to patent applicants and/or patent assignees. Essentially, any legal entity can be listed as a patent assignee on an invention. This can be an individual (natural person), corporation, university, research institute, etc.

Figure 6.1.8: Distribution of patent assignee type (1986-2015)



Source: PATSTAT, EPO; author's calculation.

Figure 6.1.8 illustrates that majority of patent assignees in the North are companies. Here, public includes university, not for profit organizations, and hospitals, while "NA" indicates that those patents have been assigned to individuals rather than public and/or private entities.

These findings reiterate that the majority of knowledge – as proxied by patents - entering the Norths innovation ecosystem is produced by private corporations. In fact, a third of the North's patents can be attributed to only 10 private corporations.[112] Since the 1990's though, public entities have emerged as a consistent knowledge generator.

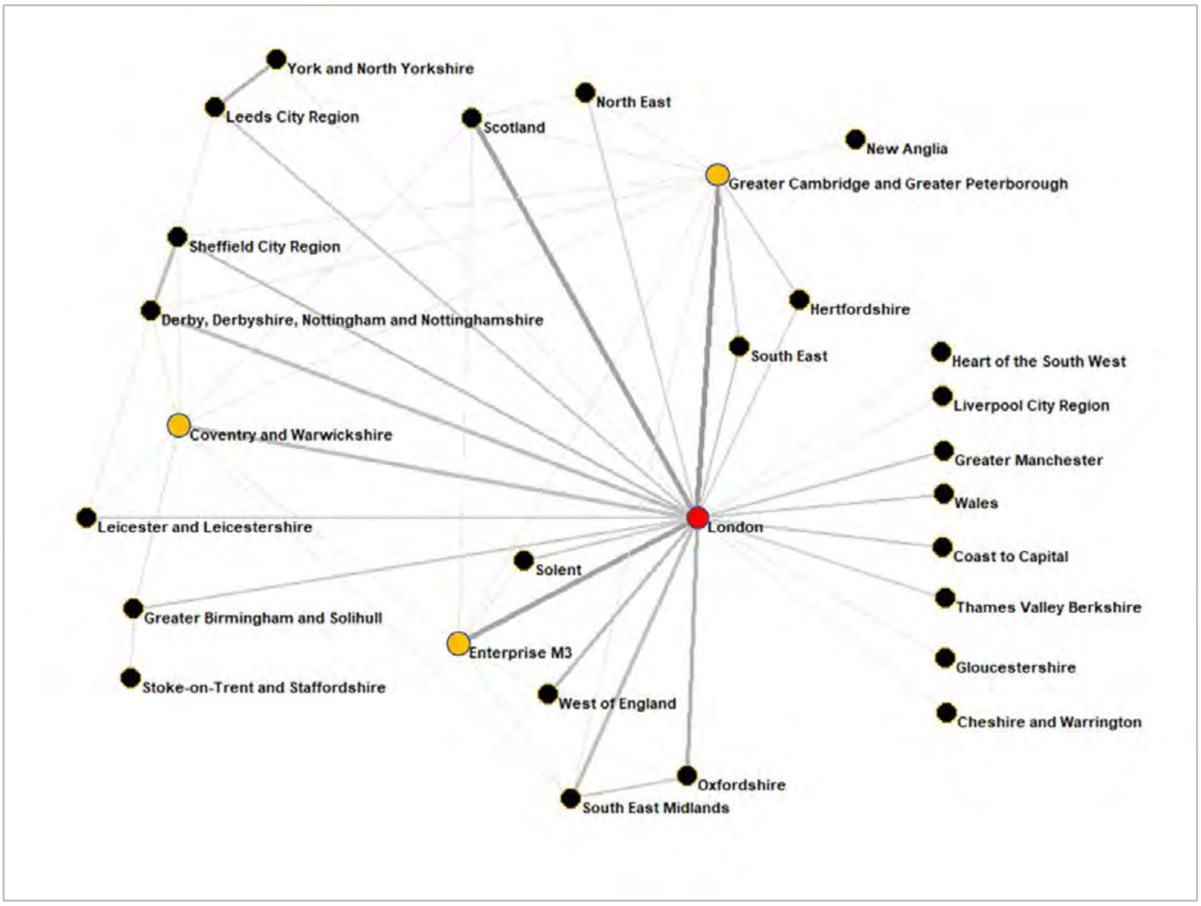
6.2 Innovate UK-funded research collaborations

An alternative source of data to patent co-inventions is the the database of projects receiving Innovate UK funding. This database runs from 2003 to 2018, and allows us to identify collaboration networks through joint funding applications by different organisations, based in different LEP regions.

In order to generate a coherent network graph, a cut-off was introduced at 100 co-applications over the 15-year period. Connections above this threshold are shown with an edge on Figure 6.2.1 below, with stronger connections above this threshold showing as thicker lines; LEP regions with 6 or above connections are shown with nodes marked in yellow, and 10 or above in red. The exact location of nodes are not quantitatively significant; they are arranged to allow maximum visual clarity as to the pattern of connections.

[112] See Appendix C8.

Figure 6.2.1: Network graph of collaborative research projects



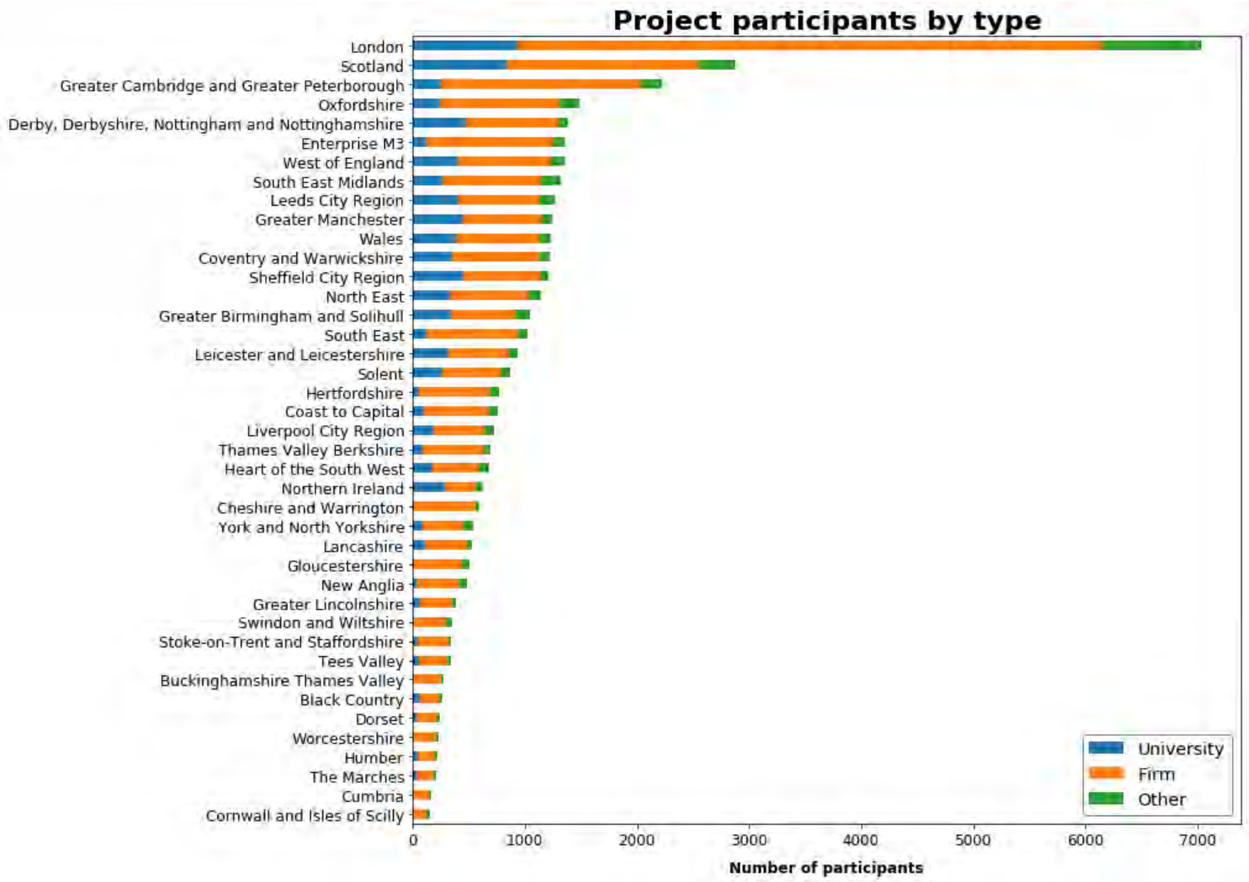
Source: Innovate UK; author's calculations.

The pattern here is clearly different to figure 6.1.4; the network is more centralised around London, with almost every LEP having London as their main collaboration partner by this measure. Other nodes with 6+ connections act as mini-regional hubs: Enterprise M3 in the south, GCGP in the east, and Coventry and Warwickshire in the midlands. Sheffield City region is the closest to a northern hub, with 5 connections, albeit only one of these is to another northern LEP area (Leeds)

Figure 6.2.2 shows the total number of collaborative research projects by LEP; The Southern LEPs are less dominant in the top 10 here, with several Midlands LEPs also featuring. Northern LEPs tend to feature in the middle of the chart. The leading Northern LEPs on this measure are Leeds and Greater Manchester. Universities are denoted in blue, private firms in orange, and other participants, which include local authorities, public research institutes and catapult centres or similar. London and Scotland have high levels of public and university involvement, whereas other strong Southern LEP areas, such as GCGP. Oxfordshire and Enterprise M3 participation is dominated by private firms, with less reliance on public sector institutions.

Stronger performing Northern (and Midland) LEPs have higher levels of university involvement than Southern LEPs, however this is not true of all Northern LEPs, with those with lower levels of overall participation also having lower relative levels of university sector participation. Cheshire & Warrington is something on an exception here. This may indicate the role of the university sector as an important leveraging factor for increasing the involvement of local firms. However, *in general*, Northern and Midland LEPs appear to be more reliant on university and public sector involvement than Southern LEPs – with the notable exception of London.

Figure 6.2.2: Total collaborative research projects by LEP, by participant type



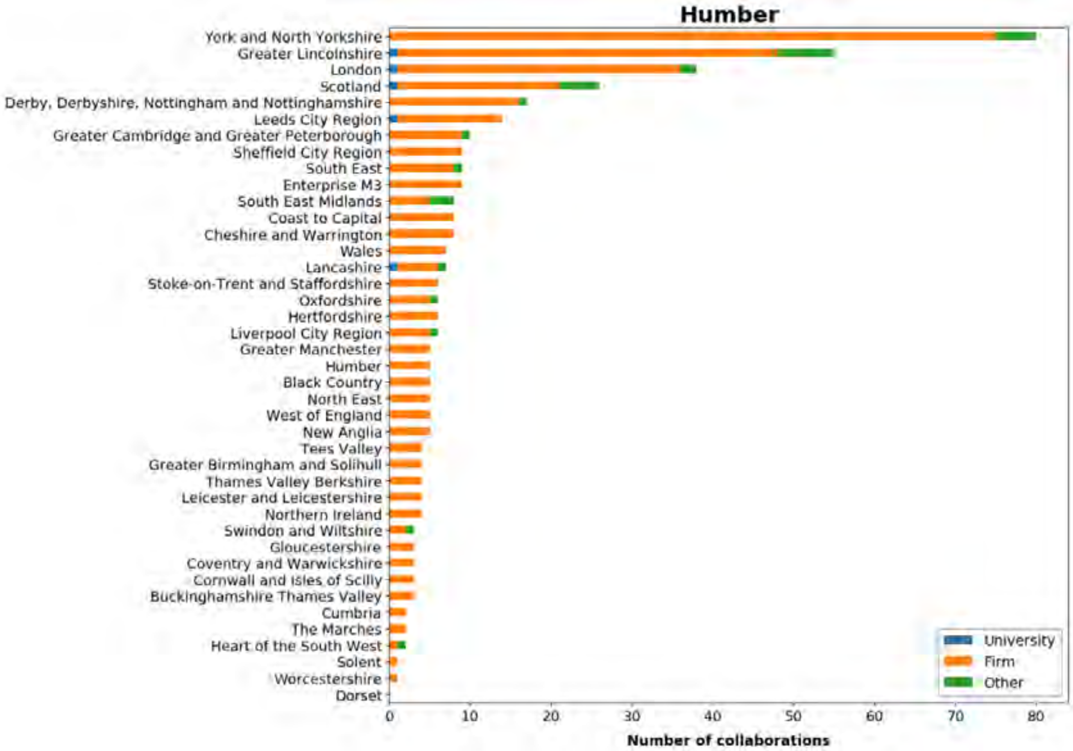
Source: Innovate UK; author's calculations.

Generally, across all LEP areas, collaboration is typically highest with London-based partners (which to some extent may reflect firm HQ bias, but also the prevalence of public and academic partners in London). Unsurprisingly, local (i.e. intra-region) collaborations are also highly evident, as well as more distant (i.e. inter-region) collaborations with innovation leaders/R&I asset rich areas (e.g. Cambridgeshire and Peterborough, Derbyshire and Nottinghamshire).

A breakdown of leading funding partners by type for each of the 11 Northern LEP areas is presented in Appendix D2. Two examples are given below.

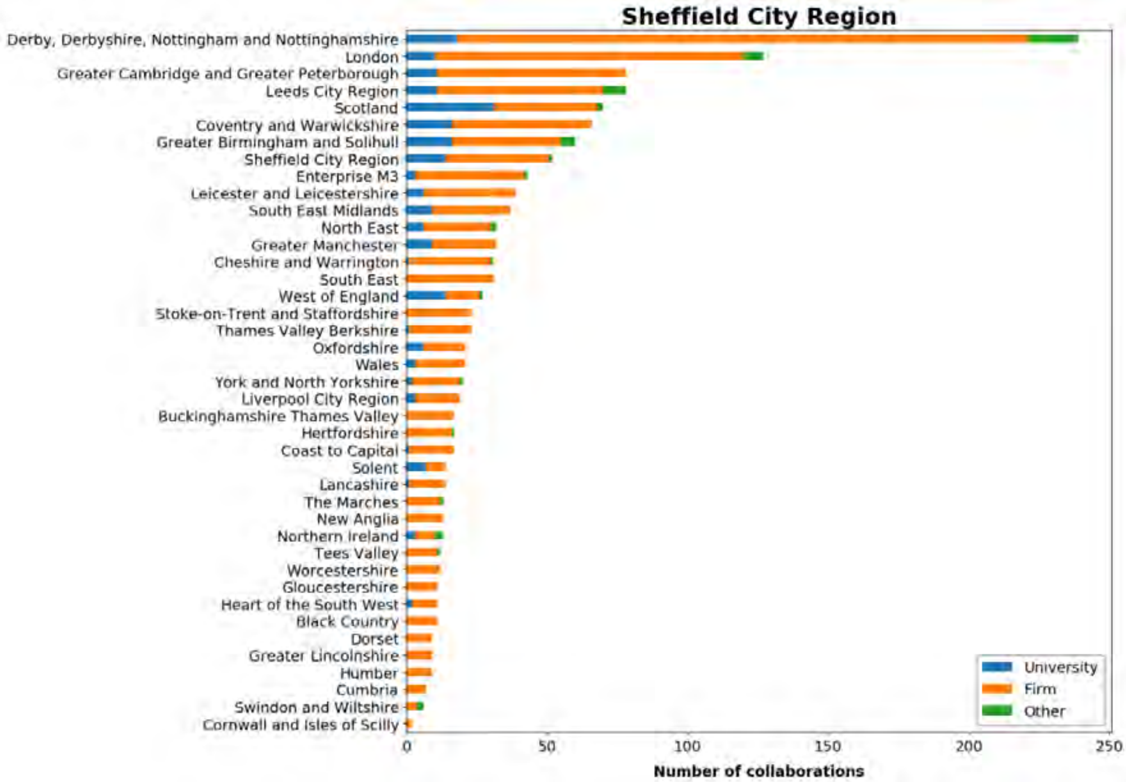
- **Humber:** high reliance on local networks is evident in the Humber, with York and North Yorkshire and Lincolnshire the leading partners. Humber's relationship with Scotland, reflecting clean energy assets and linkages, is also visible. The majority of collaborations from within the Humber LEP are by private firms, although non-university public sector bodies are involved in collaborations most prominently with York and North Yorkshire, Greater Lincolnshire and Scotland.

Figure 6.2.3: Innovate UK funded collaborations by participant type, Humber



- **Sheffield City Region:** neighbouring Derbyshire and Nottinghamshire account for the majority of Sheffield's collaborations, closely followed by London. Leeds is another popular local partner, with linkages evident with other parts of the Midlands and South. The role of the university sector in collaboration within the LEP area is visible here.

Figure 6.2.4: Innovate UK funded collaborations by participant type, Sheffield City Region



Within-North collaboration

Table 6.2.1 shows the within-North connections of the 11 LEPs comprising the region, including within-LEP collaborations. As the connections are symmetric, only the top-right half of the matrix is filled in.

Most noticeably, the degree of sub-regionality is also no longer evident – organisations from Cheshire & Warrington collaborate most frequently with their neighbours in Greater Manchester, but they also frequently collaborate with organisations from Lancashire, Liverpool, Leeds, Sheffield, the North east and York & North Yorkshire. As we saw from the network map above, the spatiality of co-applications for Innovate UK funding data seems to be more national in nature than the more localised patent production process.

Table 6.2.1: Collaborative research projects among LEPs in the North of England

	Cumbria	Cheshire and Warrington	Greater Manchester	Humber	Lancashire	Liverpool City Region	Leeds City Region	North East	Sheffield City Region	Tees Valley	York and North Yorkshire
Cumbria	2	5	11	2	9	5	8	14	7	4	2
Cheshire and Warrington		37	54	8	25	40	44	30	47	12	26
Greater Manchester			73	9	26	41	54	47	52	19	19
Humber				9	7	12	28	9	18	5	83
Lancashire					31	22	18	14	23	6	10
Liverpool City Region						48	44	26	37	7	17
Leeds City Region							115	55	112	22	318
North East								104	49	47	30
Sheffield City Region									114	28	32
Tees Valley										28	10
York and North Yorkshire											51

Source: Innovate UK; author’s calculations.

7 A Case Study of Clusters in the North

7.1 Rationale

Industrial clusters are commonly defined as geographic concentrations of interconnected firms within a specific industry, supported by specialised suppliers, service providers, firms in related industries. These actors are often connected by dedicated cluster organisations or are linked by other types of associational ties, and are plugged into vibrant and prolific knowledge infrastructures.[113] Clusters are crucial to economic and innovation policy to the extent that they are one of the fundamental geographies of innovation and are a key contributor to productivity.[114] As a result, clusters, agglomeration economies, and place-based policies have been important components of the evidence base linked to the NPIER and subsequent reports on innovation in the North of England. Clustering and agglomeration were also core themes for this project, which, among other things, asked about the importance of clustering and an evaluation of how the innovation functions differently across different sectors and industries.

In Phase 1 of this research we constructed a framework - a logic map - to conceptualise the innovation process, its drivers, and its enablers. While that work included an evaluation of how the LEPs performed on these elements we were limited in our ability to demonstrate the systemic dimensions of the logic map and in our capacity to engage with spatial geographies (e.g. exploring the significance of the distribution and concentration of pan-Northern economic activities).

Driving questions:

- How does applying the logic map help to identify strengths, gaps, and opportunities for clusters in the North?
- How do the strengths and functions of the cluster relate to others in the region and the country? Can a better understanding of how the localised clusters perform and function with respect to the logic map and each other uncover potential opportunities arising from complementarities and synergies with other regionally and nationally significant sectors?
- How do stakeholders perceive that challenges associated with COVID-19 might affect the cluster and the opportunities and constraints that it faces as it plans for the future?
- How can TfN, in partnership with local, regional, and national stakeholders, influence the development of cluster strategy to fill gaps and leverage opportunities?

Our objective is to provide a snapshot of a curated set of clusters, selected in partnership with TfN (and others as appropriate, including NP11). We propose

[113] See Porter, M. (1998). Clusters and Competition: New Agendas for Companies, Governments, and Institutions. H. U. B. School, among others.

[114] See Spencer, G. M., et al. (2010). "Do Clusters Make a Difference? Defining and Assessing their Economic Performance." Regional Studies 44(6): 697-715.

this as a cluster evaluation exercise using the logic map as a framework in combination with a foresight evaluation methodology developed with Innovate UK to understand the evolution of and planning and policy challenges in the UK national space cluster ecosystem. The advantage of this approach is that it involves developing a methodology to apply the logic map to evaluate and understand specific cases. Adopting the Innovate UK methodology in conjunction with this allows us to situate these patterns in relation to cluster life cycles and explore their connections to and embeddedness in the innovation ecosystems of regionally and nationally significant sectors.

Our intention is not to replicate previous research already in the evidence base or to engage in a deep analysis of each case study. However, this research will provide a sketch of cluster activities with reference to the logic map and evaluation tools, assess alignment of cluster planning strategies relative to the map and planning objectives (additionally adopting a COVID and post-COVID lens), and situate the cluster in the broader Northern and national economy and ecosystem. To the extent that sectors and clusters anchor the North's economic development strategies, this approach demonstrates the value of applying the logic map to different geographies and considers development as embedded in systems at different scales (localised/cluster, regional, national) in order to generate policy insights.

This research focuses on three very different clusters - digital health information systems in Leeds City Region, offshore wind energy in the North East, and chemicals and process industries in the North West. Based on these case studies, we argue that there is an opportunity for TfN and the NP11 to work together to develop localised networks of innovation to enhance cluster growth and resilience, but also to build and strengthen links (industrial, public, associational, and academic) across jurisdictional boundaries to leverage assets across the North to support cluster evolution. This research also affirms the need for a focus on supporting SMEs and points to a deeper role in advocacy at the national level and in regional programme design and development.

7.2 Methodology

Case selection

After a process of internal research and deliberation with the project's Steering Group we settled on three case studies:

Table 7.2.1: Cluster case studies and secondary clusters in the NP11

Cluster	Primary cluster location	Specialties	Secondary cluster location(s) in the North (specialties, if applicable)
Digital Health	Leeds City Region	Digital health information systems and data analytics	Greater Manchester
Process Industries (Chemicals)	North West (Greater Manchester, Cheshire and Warrington, and Liverpool City Region)	Chemical manufacturing and supporting services	Tees Valley and Durham, Humber
Offshore Wind	North East (Tyneside - Blyth)	Balance of plant / Operations & Maintenance	Hull (O&M, logistics), Liverpool

Cluster sectors

The North is home to a number of world-leading, nascent, and established clusters offering us a rich list of potential case studies. We surveyed documents in the evidence base and drew on core sectors identified in LEP documents (primarily strategic economic plans and, where available, local industrial strategies and independent economic reviews) to generate our initial list of clusters. Our aim was to highlight at least 3 clusters of national or global significance in the North to better understand the influence of ecosystem contexts using the logic model, focusing on the alignment between cluster planning and real and perceived gaps, and exploring the dynamics of existing and potential for deepening relationships with other regional and national clusters in the same or similar sectors. In narrowing our field of inquiry to three cases we were guided by the following selection criteria:

1. Alignment with NPIER capabilities and drivers
2. Geography and spatial morphology
3. Focus on different phases of the innovation process

Alignment with NPIER capabilities and drivers

In order to ensure consistency with the existing (and growing) evidence base, we wanted to ensure that our shortlist spoke to previously identified prime and enabling capabilities. This was largely driven by the Northern Powerhouse Independent Economic Review (NPIER)[115], which identified the capabilities presented in Table 7.2.2.

[115] SQW and Cambridge Econometrics (2016). The Northern Powerhouse Independent Economic Review.

Table 7.2.2: Core capabilities

Primary capabilities	Enabling capabilities
Advanced Manufacturing	Financial and Professional Services
Energy	Logistics
Health Innovation	Education
Digital	

Source: NPIER (2016)

While our clusters are not perfectly aligned, they do touch on all of the primary capabilities. Digital health combines elements of digital and health innovation capabilities. Process Industries are exemplars of advanced manufacturing, while offshore wind represents the energy sector.

Geography and spatial morphology

We also wanted to ensure that our clusters were not all concentrated in one LEP or subregion of the NP11 so that we could explore a range of innovation ecosystems. As such, our selections aimed for diversity in that both the physical location of the core cluster and the locations of secondary centres and gave some consideration to distribution across the East and West of the region. We also wanted to select cases with different spatial morphologies, including sectors that will tend to be more densely concentrated in urban areas (eg. digital health), centred on urban areas but with the potential for dispersion into suburban and peripheries of urban areas (eg. process industries), and that may be more broadly dispersed across non-urban parts of the region (eg. offshore wind). Selecting clusters with these different characteristics enables us to explore the role of space and connectivity in more detail than more uniform geographical or spatial case selection strategies.

Focus on different phases of the innovation process

Given the structure of the logic map of the innovation process developed in the first phase of this project, we were particularly interested in exploring clusters that might have natural strengths at different stages. While details about the strengths and gaps for specific clusters emerged as part of the cluster evaluation and assessment process, it was possible to infer where each cluster is likely to concentrate its expertise. This inference can also be refined with knowledge about the types of firms and anchor institutions in the cluster and broader ecosystem. More knowledge-intensive clusters based around universities, such as chemicals processing, will likely have strengths in the knowledge creation phase of the innovation process. Industries like offshore wind, which are based around large firms and a strong Catapult are likely to have strong pipelines at the value creation stage of the process. Clusters like digital health may exhibit strength more evenly across the innovation process as innovating firms are likely to be co-located with their markets such as hospitals, care providers, and government agencies involved in health policy.

Of course, these clusters also vary on a range of other factors such as skills profiles, international orientation, age and maturity, and core types of innovation, among other factors. We thought that this wide range of variation will provide three interesting and salient vignettes of how clusters function in the NP11 economy and enable us to highlight both context-specific patterns and, more importantly, cross-cutting themes to guide TfN's innovation policy interventions.

Cluster boundaries and geographies

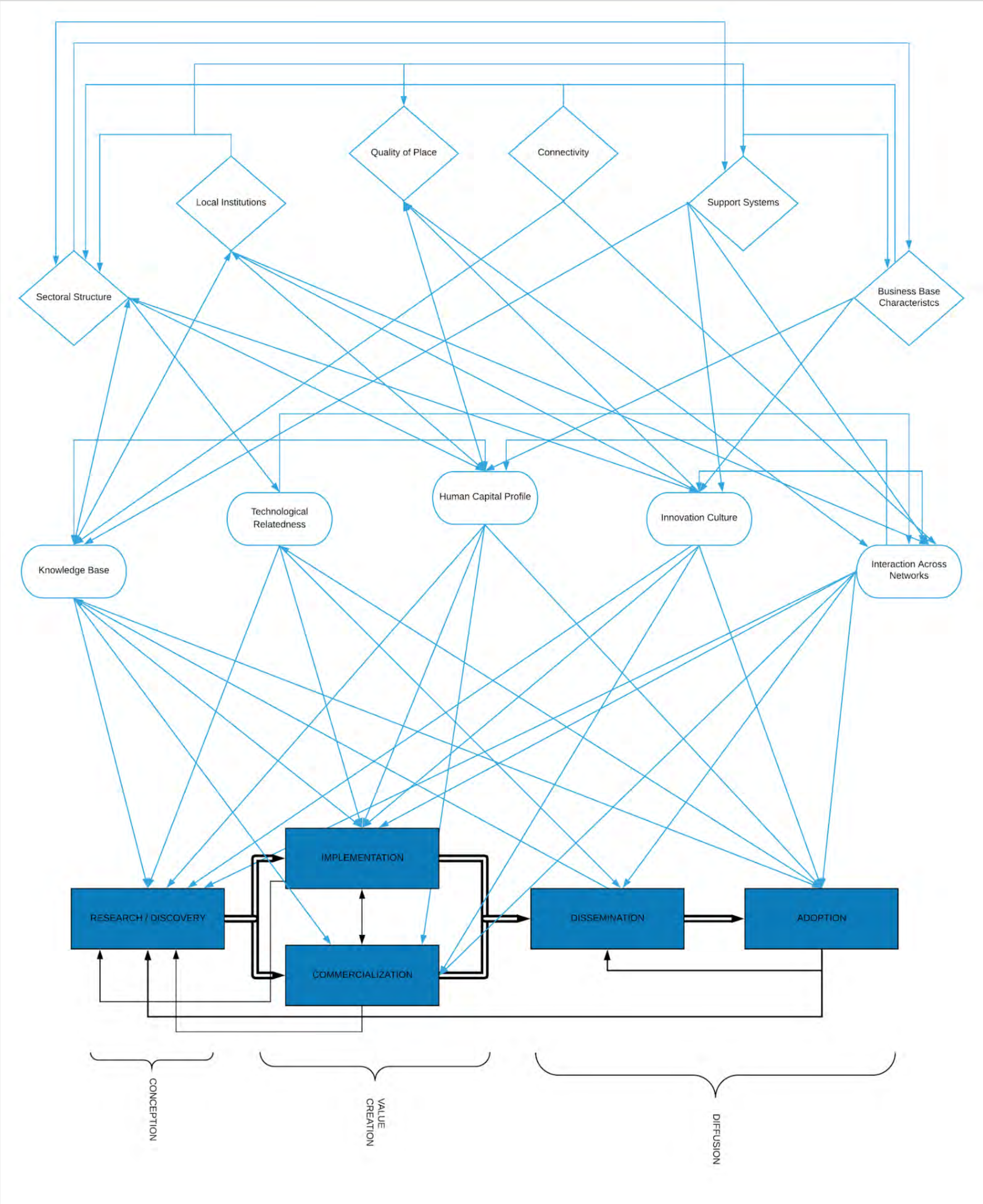
For each of the cluster sectors selected above we can identify several potential clusters in the North. For instance, while the chemical and process industries sector has a historical strength in the eastern part of the region (particularly in Humber and the Tees Valley) it also has a critical mass in the west in the area surrounding Greater Manchester. For this study, our objective was to focus on one specific cluster within the North to understand its unique ecosystem and relationships with other clusters in the sector in the region and around the country. Our selection criteria for geographical focus mirrored some of the considerations above - namely, geographical diversity and cluster coherence - but was also guided by the practicalities of data collection and informed by the boundaries established by previous research on the spatial dynamics of the sector. Accordingly, we began the selection process by initially selecting clusters within a single LEP or group of contiguous LEPs, identifying sub-LEP hotspots, and collecting a first round of descriptive indicators.

Ultimately, we decided to adopt the North West, North East, and central (Leeds) locations to ensure diversity across the region and because of the dynamism of the clusters. We adopted the boundaries established by previous studies and/or cluster organisations.

Applying the logic model

One of the core objectives of this part of the study focuses on assessing clusters in the North using the logic map developed in Phase 1 of the project. Doing this demonstrates the value of engaging in cluster analysis using a systems-inspired framework, which allows us to highlight unique patterns of cluster development and pinpoint combinations of drivers and enablers that might be appropriate areas for strategic intervention. We supplement this approach with the cluster assessment tool developed for Innovate UK by the Innovation Caucus, which particularly focuses on assessing cluster life cycle stage, market positioning, and provides a framework for cluster planning based on identified goals and gaps. Finally, while this was not part of the original assessment tool, we are inspired by the Innovate UK approach to analysing the individual clusters that make up the UK space innovation ecosystem and their relationships to one another. The report makes the case that as cluster planning proceeds there is value in individual clusters recognising and planning around their different roles in the national ecosystem. This argument may resonate in the NP11 context where the improving coordination and connectivity between different clusters in the same industry with overlapping and complementary specialisms may provide an opportunity to accelerate cluster development.

Figure 7.2.1: Innovation process logic map



The logic map originally aimed to demonstrate the systemic nature of the interrelationships and interactions that make up an innovation ecosystem. The systems dynamics models that inspired this approach not only demonstrate relationships between elements but specifies type of impact (positive or negative) and, ideally, approximate magnitude of influence (major or minor). Working only at the conceptual level in Phase 1, we proposed a series of metrics, drivers, and enablers and outlined a set of relationships between them anchored in a review of innovation literature. While we could populate this map with indicators to compare LEPs within the North the data itself (in this format) could not tell us much about the nature or significance of the relationships. The best we could do was to treat the impact of all the drivers as about equal while suggesting that the way that they acted on each of the metrics (and each other) differed. More specificity than that was difficult given data and time limitations, and this limited our ability to draw conclusions about causal relationships and interventions.

Scaling the map down to the cluster level and complementing the data with expert interviews allows us to highlight interactions between the map elements with more confidence. Crucially, it permits us to do what the data alone could not - to identify pinch points and critical pathways. Interpreting these with reference to TfN's competencies to act - both alone and in partnership with other stakeholder - suggests points of intervention for each cluster. And considering similarities and differences between the case study pathways points to broader-based policy lessons.

In this phase, we use the logic map as a conceptual tool to guide our cluster research. Through interviews with key stakeholders in each cluster we explore cluster innovation processes and identify the influence of drivers on the different phases. By prompting descriptions of driver influence and interactions, strengths and gaps, we highlight weaker links and trace their origins to enablers and other drivers. Through this process, we begin to develop an understanding of the pathways - from driver to metric and enabler to driver - that may yield opportunities for greater efficiencies.

The questions that emerge from this approach share many similarities with the Innovate UK methodology to the extent that both focus on identifying the core assets, advantages, and challenges in an innovation ecosystem. However, we supplement the logic map framework with two elements from that methodology - an explicit focus on cluster life cycle characteristics and the degree to which clusters are embedded in broader national innovation systems. First, we suggest that strengths and gaps might be functions of cluster maturity and aim to situate these findings in the context of evolutionary economic geography. Second, we include questions about engagement with markets and function within supply chains relative to other clusters to understand their position in national networks of related clusters and the national industrial landscape. These two perspectives add context to the drivers of the logic map and explain and contextualise observed patterns and can contribute strategies for cluster development.

While applying the logic map in this manner allows for greater depth and detail of analysis of these pathways for intervention due to project time constraints these are best interpreted as vignettes - illustrations of the potential of these tools and of adopting a systems-inspired framework. What we can produce from this depth of analysis are a series of suggestions about areas of opportunity for policy but we are limited in the degree to which we can, as a result, propose concrete policy solutions. The limits of our interpretation will be acknowledged throughout the report. However, it is useful to bear in mind that all of our findings should be seen as an invitation to stakeholders to engage in discussion around those areas and to consider more research where appropriate. Despite these limitations, our conclusions do reveal some interesting patterns and demonstrate the utility of the logic map as a tool for understanding regional economic and cluster dynamics around the innovation process.

Finally, while the timing and focus of the project precludes a deep investigation of the impact (and potential impact) of COVID-19 it is impossible to ignore. We can, through this research, make an initial foray into exploring the broad thematic areas that are likely to influence cluster evolution in the short term. These questions are not central to our analysis, but the impact of COVID-19 will be discussed where appropriate.

Case Studies Overview

The following section presents the detailed cluster case studies. Here we focus on unpacking three main themes. After introducing and situating the cluster, we elaborate **cluster specialisation and core assets**. Our objective here is to highlight strengths and establish the knowledge assets that anchor the region with particular reference to the logic map drivers and enablers. In the **critical pathways** section, we highlight a key driver or enabler that emerged from our interviews as a pinch point or hinderance to the innovation process. We then attempt to explore the roots of that bottleneck with reference to linked drivers and enablers. Understanding these critical points as well as their relationship with other elements of the innovation system allows us to explore context and can enable us to more effectively pinpoint avenues of intervention. Finally, we explore the **clusters' function in and connection with national and regional innovation ecosystems**. Here we expand our analysis to understand how the cluster relates to complementary and competing centres of expertise in the same sector. The objectives here are to look beyond the clusters' immediate boundaries for advantages, to ensure that cluster foresight and development activities leverage local specialisms to contribute effectively to national ecosystems, and to identify opportunities to better connect assets across the North of England to grow a pan-Northern sector.

Each of these cluster case studies was designed to stand alone, for those interested in focusing on specific sectors and themes. Readers familiar with the clusters may wish to skip to Section 7.6 where we provide a synthesis of our findings before proceeding to a discussion of policy implications. Before proceeding, we offer a final reminder - these are not comprehensive cluster case studies. Our objective here was to evaluate the cluster and draw preliminary policy conclusions using the tools developed in the course of this project. We owe a great debt to much more comprehensive research, such as previous cluster case studies and science and innovation audits, which we reference liberally throughout this section. These vignettes enable us to highlight the power of the logic map tool and demonstrates the value of a systems-inspired approach focused on critical pathways rather than siloed policy areas. While we can, and do, draw conclusions from this research, it should be interpreted with these caveats in mind.

7.3 Leeds City Region Digital Health Information Systems Cluster

The digital health sector in the UK is an important segment of the medical technology sector, growing by over 10% per annum[116]. Digital health sits at the intersection of healthcare, information technology and mobile technology and is the largest employer within Medical Technology with over 10,000 people, generating over £1 billion in revenue. Globally, growth is expected to increase due to the COVID-19 pandemic which has placed increased pressure on healthcare systems and increased the awareness and use of digital healthcare solutions[117].

Historically, the digital health sector in the UK has been good at generating ideas, but less successful at commercialising them[118], with the majority of firms relying on UK markets rather than exports[119]. The COVID-19 pandemic has led to rapid implementation of many digital health products and the need for a streamlined evaluation system[120], which has supported drives to improve commercialisation. In Leeds, the internet exchange hub - a point of convergence of fibre optic cables and a key node of digital infrastructure - served as powerful attractor of firms that rely on low-latency data access and led to the development of capabilities in informatics across the financial and health sectors. The prevalence of these skills in Leeds, combined with the low capital requirements to develop digital health solutions, offers an opportunity to drive commercialisation through startups.

However, the Leeds City Region is not the largest centre of digital health activity in the UK (see Figure 7.3.1[121]) even though the Leeds City Region, encompassing Leeds, Bradford and York, make up the largest economic area outside of London[122]. Rather, it acts as a regional counterbalance to the

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[116] Department for Business, Energy and Industrial Strategy and Office for Life Sciences [BEIS and OLS] (2017). Strength and Opportunity 2017: UK digital health segment. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/707079/digital-health-infographic-2017.pdf

[117] Strategy& (2020), Will COVID-19 jumpstart the digital healthcare revolution? https://www.strategyand.pwc.com/de/de/studien/2020/digital-healthcare/will-covid19-jumpstart-the-digital-healthcare-revolution.pdf

[118] Deloitte (2015). Digital Health in the UK An industry study for the Office of Life Sciences, BIS/15/544 – Digital health industry study: UK market analysis. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/461479/BIS-15-544-digital-health-in-the-uk-an-industry-study-for-the-Office-of-Life-Sciences.pdf

[119] National Institute of Economic and Social Research (2017). Industrial Clusters in England. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/646547/NIESR_Clusters_Research_BEIS_Format_with_summary_FINAL.pdf

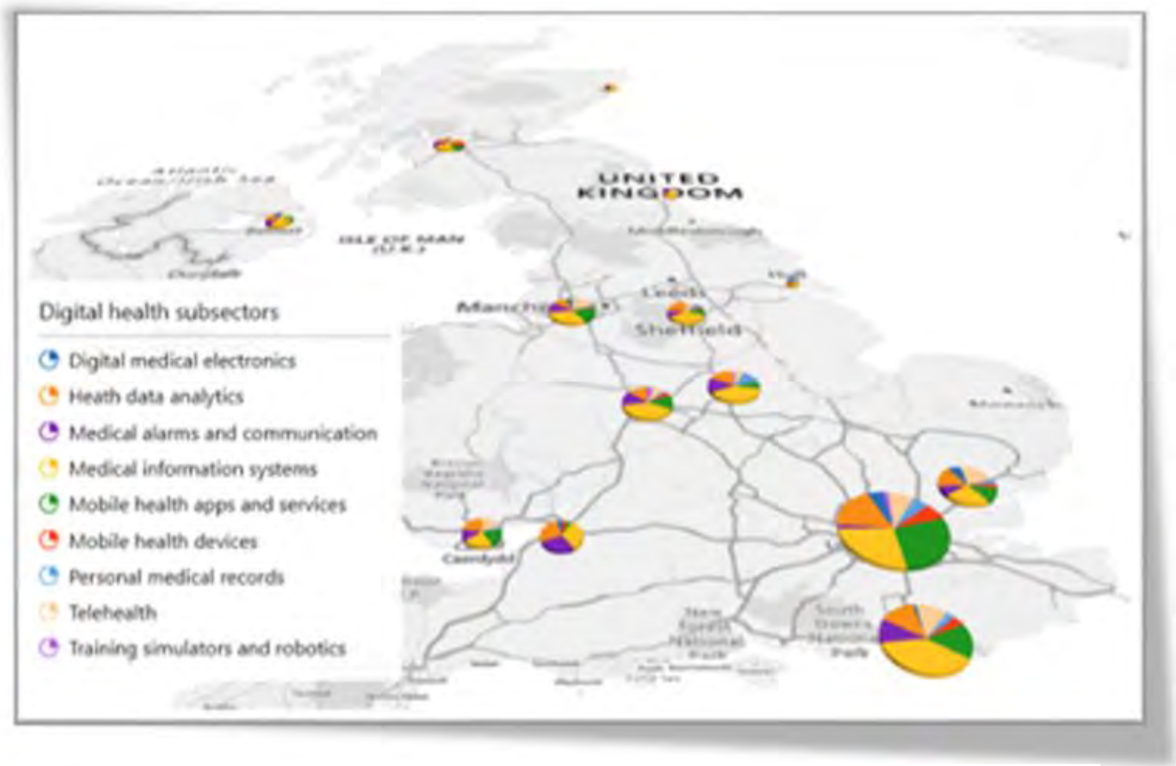
[120] Public Health England (2020). Rapid evaluation of digital health products during the COVID-19 pandemic. https://www.gov.uk/guidance/rapid-evaluation-of-digital-health-products-during-the-covid-19-pandemic

[121] Office for Life Sciences (2018). Bioscience and health technology sector statistics. https://www.gov.uk/government/statistics/bioscience-and-health-technology-sector-statistics-2018

[122] University of Leeds (2017). Opportunities and growth: Medical technologies. https://leedscityregionmed.tech/Leeds_medtech_SIA_web.pdf

South, supporting 22% of the digital health employment, with London (23%) and the South East (20%) comprising the majority of employment.

Figure 7.3.1: Map of concentrations of digital health activity in the UK



Source: Office for Life Sciences (2018).

The Leeds City region hosts a robust innovation infrastructure with NHS Spine, the digital backbone of the NHS, and the Medical Technologies Innovation and Knowledge Centre at Leeds University. These support over 250 medical technology firms in the region[123], although only 19 of these are within the digital health sector[124]. The digital health sector in Leeds is therefore considered embryonic/emerging.

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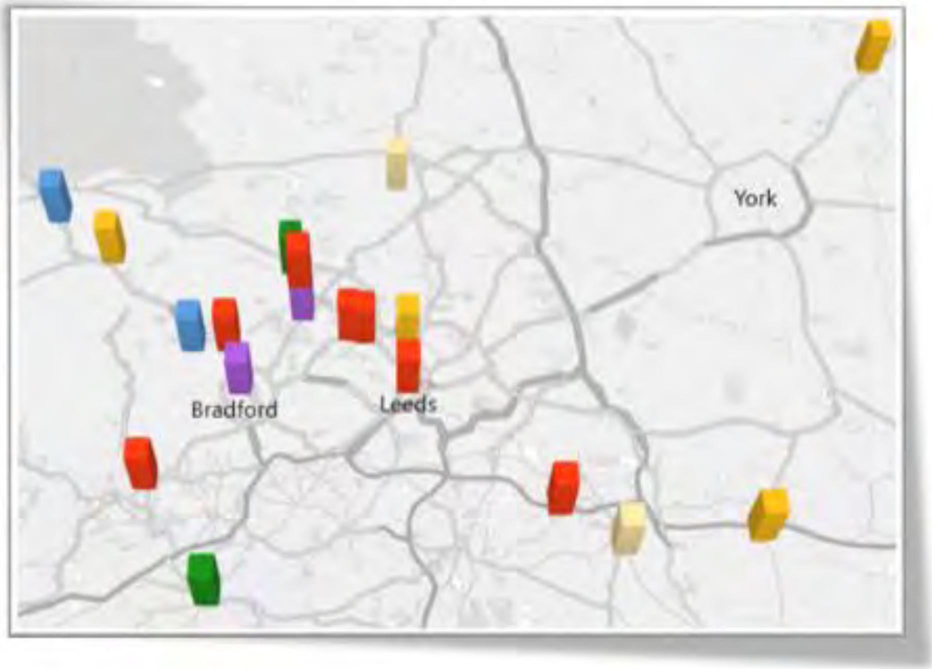
[123] University of Leeds (2017). Opportunities and growth: Medical technologies. https://leedscityregionmed.tech/Leeds_medtech_SIA_web.pdf

[124] Office for Life Sciences (2018). Bioscience and health technology sector statistics. https://www.gov.uk/government/statistics/bioscience-and-health-technology-sector-statistics-2018

Figure 7.3.2: Map of digital health firm specialisations across the Leeds City Region



Source: Office for Life Sciences (2018).

Our research reveals that Leeds City Region digital health is a cluster with strong foundations and impressive growth potential. However, viewed through the lens of the logic model, scope exists to improve performance across the innovation process by enhancing the networking of startups with existing structures to more effectively draw innovation out from its impressive knowledge base.

Specialisation and main cluster assets

The digital health sector is generally conceptualised as having several key segments, which differ in their maturity, growth potential and prevalence across regions. Hospital and GP information systems, together with data analytics using the information from those systems, comprise 72% of employment within the digital health sector[125]. Other significant segments include tele-health (monitoring and diagnosis), and mobile health apps. While the Leeds City Region appears to support activity in all of these sub-segments, there appears to be more activity in information systems and data analytics compared to London, which has a comparative strength in mobile apps, or the North West, which has higher telehealth related activity. The emphasis on information systems and data analytics in the Leeds City Region fits well with the location the largest consumer of these products: NHS Spine and NHS Digital, both with a strong presence in Leeds. NHS Spine is a portal that connects over 23,000 healthcare systems in 20,500 organisations[126]. It is developed and maintained by the Digital Delivery Centre in Leeds which also manages the national infrastructure platform for other services such as the Care Identity Service and Secondary Uses Service. In addition, NHS Digital's

[125] Department for Business, Energy and Industrial Strategy and Office for Life Sciences [BEIS and OLS] (2017). Strength and Opportunity 2017: UK digital health segment. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/707079/digital-health-infographic-2017.pdf

[126] NHS Digital (2020). Spine. https://digital.nhs.uk/services/spine

office in Leeds employs over 6000 to collect national data on the NHS and social care, and compiles over 250 publications each year,

Innovation from Leeds University is connected through links to the NHS in the city, some of which occurs through co-location (e.g. Leeds General Infirmary) and some through networks such as the Leeds Academic Health Partnership, which in August 2019 supported a new agreement to streamline the testing of new ideas, followed by their adoption and diffusion[127]. The Leeds Academic Health Partnership is a network developed in recognition of the need to bring together universities and the health and social care system in order to speed up adoption of research.

Other universities such as the University of Bradford and York University within the Leeds City Region are also connected through similar partnerships such as the Yorkshire & Humber Academic Health Science Network, and most recently, the Digital Health Enterprise Zone in Bradford. Together, universities in the Leeds City Region are attracting 8% of total EPSRC funding for medical technology research[128].

The digital health sector in the Leeds City Region is related to the information technology and financial sectors which all rely on informatics capabilities and underpinned by a strong medical technology sector. Together with the headquarters for Sky Digital, a strong financial sector underpinned by a low latency internet node and internet exchange, the NHS Digital and NHS Spine attract informatics skills from around the UK, outstripping digital employment growth in Bristol and Manchester[129], and enhancing the demand for digital skills. Four out of ten job postings within Leeds fall into the digital category, with software developer/engineer by far the greatest number of postings[130].

This prevalence of informatics skills forms an attractive mix for digital health startups to locate in the Leeds City Region, most recently supported by establishment of the Digital Health Enterprise Zone led by the University of Bradford and the Digital Catapult Centre, Yorkshire. The Digital Health Enterprise Zone is a £13m partnership that enables academics to support incumbent digital health firms as well as emerging SMEs via research council funding and Innovate UK initiatives[131]. However, the data[132] suggests that this has as yet translated into a relatively small number of digital health firms in the Leeds City Region.

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[127] Leeds Academic Health Partnership (2019). New healthtech agreement to help solve Region's hardest health challenges. https://www.leedsacademichealthpartnership.org/lahp-blog/new-healthtech-agreement-to-help-solve-regions-hardest-health-challenges/

[128] University of Leeds (2017). Opportunities and growth: Medical technologies. https://leedscityregionmed.tech/Leeds_medtech_SIA_web.pdf

[129] Leeds Digital Board (2016). Leeds Digital Skills Action Plan. http://www.leedsgrowthstrategy.co.uk/wp-content/uploads/2016/11/Leeds-Digital-Skill-Action-Plan.pdf

[130] West Yorkshire Combined Authority and Leeds City Region Enterprise Partnership (2018), Labour Market Report: Leeds City Region. https://www.the-lep.com/media/2282/leeds-city-region-labour-market-report-2018-2019.pdf

[131] University of Bradford (2020). Digital Health Enterprise Zone. https://www.bradford.ac.uk/dhez/research-partnerships-projects/

[132] Office for Life Sciences (2018). Bioscience and health technology sector statistics. https://www.gov.uk/government/statistics/bioscience-and-health-technology-sector-statistics-2018

Overall, this is a cluster that is in the process of establishing – a process that will likely accelerate if startups are encouraged by recent improvements in access to healthcare local markets.

Critical pathways

The Leeds City Region has several well established, large digital health companies (e.g. EMIS Health, System C, TPP, PCTI solutions), however the majority of the digital health companies within the region have under 5 employees[133]. While the digital health cluster in the Leeds City Region is well positioned to grow with support from the foundations of a strong talent base in well networked organisations that generate and test ideas, commercialisation of this innovation has been limited by an innovation culture that is risk averse to new ideas from companies without established track records.

Since clients serve as an important source of legitimacy for small firms[134], and small firms rely more on strong community relationships for survival[135], it would appear that a critical path for developing a vibrant cluster of digital health firms needs to consider their business characteristics. They are typically small, owner managed firms without substantial track record or client base. Identifying and incorporating these early stage innovators into established networks for testing, procurement and innovation diffusion can extend their community networks, enhance their legitimacy and enable increased survival and scaling for these firms.

Incorporating startups and potential digital health entrepreneurs into the established digital health networks may also help the fragmented NHS marketplace recognise the ongoing value of these products, recently experienced through the streamlined healthcare procurement processes put in place due to the COVID-19 pandemic. This may help to entrench the changes and place new value on the services available from startups and small firms.

Interviews revealed the importance of taking ownership of the community's values at a regional level, and seeking ways to influence the culture was identified as an important regional activity. There was recognition that the culture is shifting and that the conversation around values such as data privacy and risk tolerance needs to consider a wide group of stakeholders, including medical practitioners focussed on patient care, healthcare operators navigating myriad regulations, and the public.

Function in and connection with the national innovation ecosystem

As with many regions and sectors throughout the UK, the Leeds City Region's digital cluster finds itself needing to attract appropriate talent from outside the region. While salary plays a large role in this, which the region appears to be matching[136], especially after adjustments for cost of living, other pathways for talent might be explored by considering the digital health innovation landscape in the UK. For example, our interviews suggested that while Oxford plays an

[133] Office for Life Sciences (2018). Bioscience and health technology sector statistics. https://www.gov.uk/government/statistics/bioscience-and-health-technology-sector-statistics-2018

[134] Ruffo, O.I., Mnisri, K., Morin-Esteves, C. and Gendron, C. (2018). Judgements of SMEs' legitimacy and its sources. Journal of Business Ethics, pp.1-16.

[135] Russo, A., & Tencati, A. (2009). Formal vs. informal CSR strategies: Evidence from Italian micro, small, medium-sized and large firms. Journal of Business Ethics, 85(2), 339–353.

[136] Indeed (2020). Developer Salaries in Leeds. https://www.indeed.co.uk/salaries/developer-Salaries,-Leeds-ENG

important role in developing both the talent and ideas required for digital health innovation, this seems to directed South to London.

Further, interviews highlighted that there is limited interaction with Manchester which has strengths in telehealth. This is echoed in the apparent lack of coordination in establishing regional academic health partnerships. Manchester established an academic health partnership in 2009 while it took until 2016 for Leeds to follow. Nonetheless, the Manchester Academic Health Science Centre operated on approximately £500,000 per annum, while the Leeds City Region has shown strong commitment to supporting innovation adoption by funding the Digital Health Enterprise Zone with £13m. Incremental regional steps continue with Manchester's newly established institute for health technology which is funded with £5m[137]. Similar to the Digital Health Enterprise Zone, the institute aims to pull innovations through from basic research to market ready products and services, which can then be adopted by Greater Manchester's devolved health and care system. Interviews have suggested that a lack of coordination, both within and across regions, may stem from the fragmented nature of the NHS, which forms a core client in each of these academic partnerships. Establishing an interregional NHS network of digital health adoption may enable increased scaling and reduced duplication of efforts.

Analysis

Overall, the prospect for the Leeds City Region digital health cluster are promising. High growth prospects, recent lessons from the COVID-19 pandemic on improving market access for startups, and an opportunity to re-examine the culture surrounding healthcare in the UK generally, and the Leeds City Region in particular, offer a promising new landscape that can see the cluster growing from its current embryonic state.

Being cognizant of the needs of startups in this growth phase of the cluster are crucial to supporting the cluster. This means incorporating them into the established networks, associations and procurement processes within the Leeds City Region, as well as helping them to engage with stakeholders in the conversation around values surrounding privacy, patient care so that they can deliver valuable services that can be integrated into the complex healthcare system in the UK.

7.4 North East (Tyneside - Blyth) Offshore Wind Cluster

Offshore Wind Energy in the UK has been described as an unseen success story due to its peripheral geography yet rapid growth and rising significance in domestic energy production. It is already providing 8.5% of the UK's electrical energy, which is projected to rise to 35% by 2030 with a capability of providing 50% of the UK's demand in future.[138] As of 2019, more than 7,200 people were directly employed in the offshore wind sector around the country[139], and projections by Cambridge Econometrics predict that will rise to

[137] Health Innovation Manchester (2020). The Christabel Pankhurst Institute for Health Technology set to open in Manchester. https://healthinnovationmanchester.com/news/the-christabel-pankhurst-institute-for-health-technology-set-to-open-in-manchester/

[138] Whitemarsh, M. (2019). The UK Offshore Wind Industry: Supply Chain Review, Offshore Wind Industry Council.

[139] Noonan, M. (2019). UK Offshore Wind: Realising the Sector Deal Opportunity, Offshore Renewable Energy Catapult.

over 24,500 across all stages of the sector by 2024.[140] Prior to the COVID-19 pandemic, forecasts indicated that there would be £2.5 trillion invested globally in wind energy (on and offshore) by 2040, signalling that robust demand was expected for development in this sector. While the magnitude of that demand in the near term will likely be diminished by pandemic-related economic contraction it is also possible that green energy production will make up an important part of progressive national recoveries.

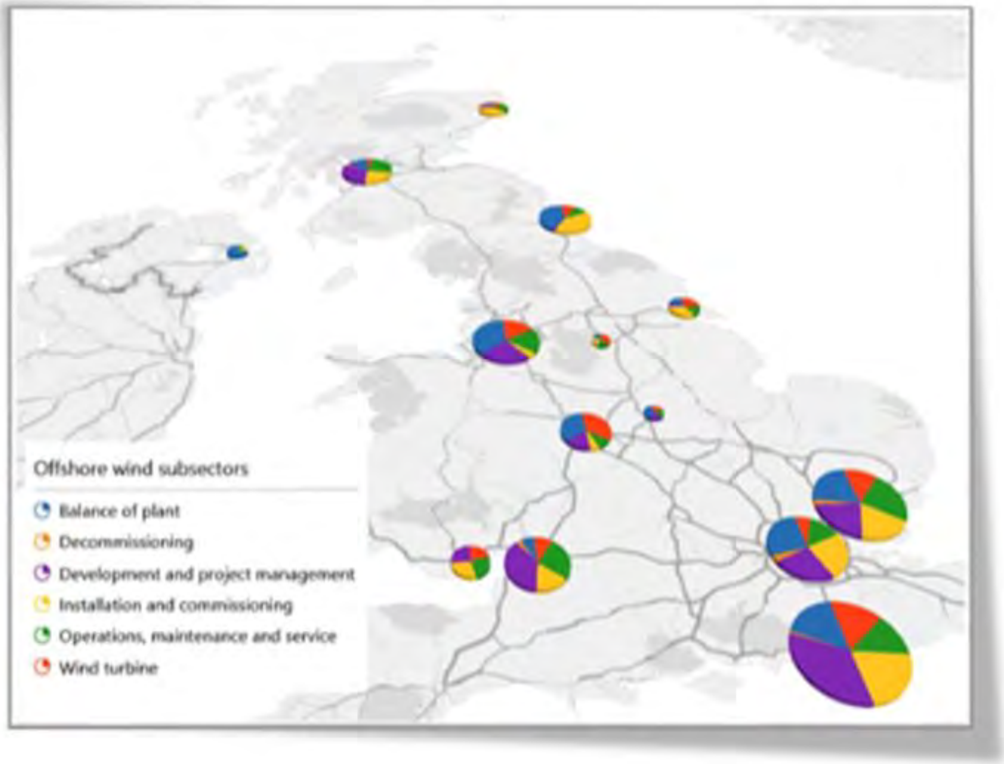
The current industrial policy lists Clean Growth as one of its Grand Challenges and BEIS recently announced a sector deal with the industry that provides forward visibility of future Contracts for Difference (CfD rounds with support of up to £557m across regularly scheduled auctions into the 2020s), which will facilitate long term planning and investment in the UK supply chain. The benchmarking requirements have provided an opportunity for the sector to think about themes related to skills, innovation, and productivity, which involve accelerating sustainable cost reduction, wider systems integration, and scaling up the supply chain. These investments and initiatives, coupled with the vibrant network of industry associations involved in realising the sector deal's potential, indicate that the process of industrial clustering in poles of offshore wind activity across the UK is likely to deepen. It also suggests that those clusters that engage in strategic development may be able to capture significant benefits of continued investment and grow their impact on local and regional economies. Following the sector deal, Energi Coast, a cluster organisation formed in 2011 was reconstituted to include broader participation and reinvigorate regional promotion and support for the industry.

Tyneside (and the North East) is not the largest centre of offshore wind activity in the UK (see Figure 7.4.1[141]) but it is one of the most significant in the North. It is difficult, in some sense, to speak of clustering in an industry partly based in the ocean. However, economic activity does tend to be centred on coastal and riparian urban areas. In the UK landscape, much of the industry is concentrated in Scotland (Glasgow, Edinburgh, and Aberdeen) and in the South. In the North, significant concentrations of offshore wind activity centre around the major conurbations of the region - most notably, Liverpool in the West and Tyneside and Hull in the East.

[140] Cambridge Econometrics (2020). Research Study into the North East Offshore Wind Supply Chain.

[141] Cambridge Econometrics (2020) - Note that the extent and location of the offshore wind industry is difficult to pinpoint for several reasons. First, it is not an industry that is easily classified by a standard list of industry classifications (SIC). Its supply chain and scope of activity spans maritime construction, manufacturing, logistics, operation and maintenance, and engages with technologies from advanced materials to remote sensing to AI. Secondly, as a decentralised industry activities occur in multiple locations - many far from firm headquarters. In this map, we've opted to aggregate activities to specific locations but these totals reflect activity for the broader surrounding region (i.e. North East activity is depicted on Tyneside, Humber on Hull, etc.).

Figure 7.4.1: Map of concentrations of offshore wind activity in the UK



Source: Cambridge Econometrics (2020)

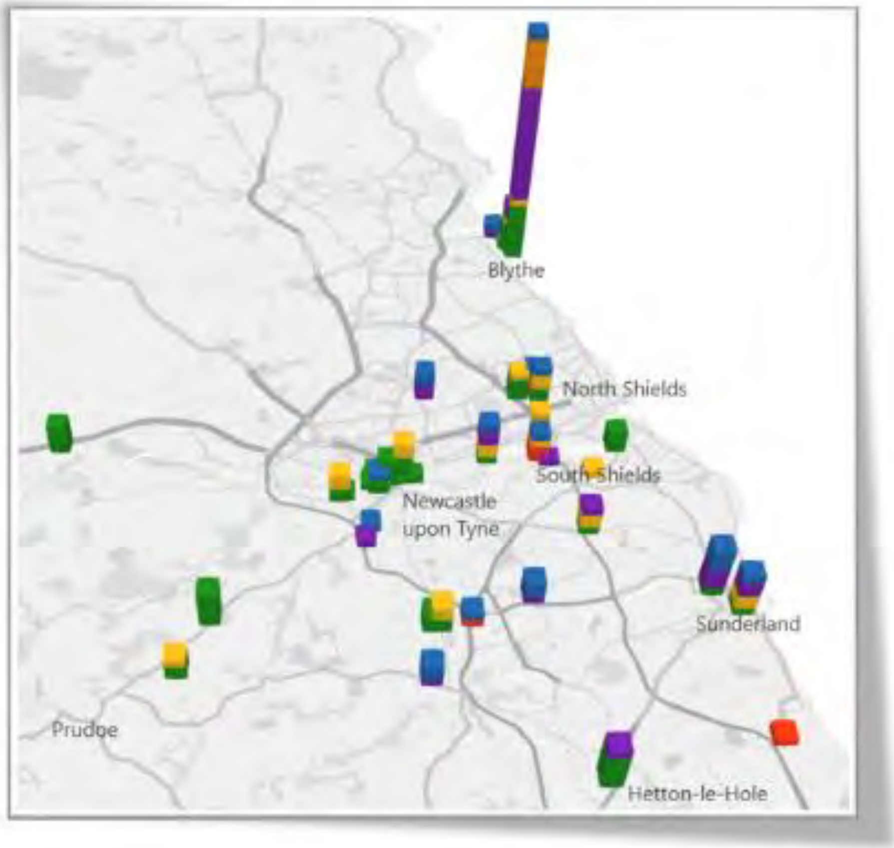
The Tyneside and Blyth areas have the most significant of these concentrations on the North East coast. The 2017 Science and Innovation Audit stated that the industry employed 15,000 people in the Tyneside area and broader North East. It is the home to over 50 firms active in the industry responsible for over £1.5 billion turnover annually.[142] The broader region hosts an impressive innovation infrastructure with research and training programmes at Newcastle University and several national research centres (see below for more detail on these assets). However, despite these strengths economic activity in this area this can be classified as a young/immature cluster.[143]

Our research reveals that this is a cluster with strong foundations and impressive growth potential. However, viewed through the lens of the logic model, scope exists to improve performance across the innovation process by enhancing networks to more effectively access and leverage its impressive knowledge base.

[142] BEIS (2017). Offshore Renewable Energy Science and Innovation Audit.

[143] Per the Innovation Caucus (2020) classification scheme.

Figure 7.4.2: Map of the main firms and subsector activities across the North East (Tyneside - Blyth) cluster



Source: Cambridge Econometrics (2020).

Specialisation and main cluster assets

Economic activity in the North East (Tyneside - Blyth) offshore wind cluster is a product of both the unique structure of the industry in the UK as well as localised assets. The sector is generally conceptualised as having several key stages - these include project development, turbine manufacturing, balance of plant, installation and commissioning, operations and maintenance (O&M) and servicing, and decommissioning.[144] While the UK has some firms involved in turbine manufacturing the plurality of firms in the sector are involved in specific areas of project development (primarily engineering consultancy), balance of plant (foundations and substations), installation and commissioning (offshore cable and logistics), and O&M. The offshore wind cluster in the North East hosts activities across these specialties with particular strength in offshore construction and O&M. While turbine manufacture tends to happen elsewhere the Offshore Renewable Energy (ORE) Catapult testing and validation facilities in Blyth is one of the largest of its kind in the world and is used by OEMs testing turbine components for installation in the North Sea (and elsewhere). The knowledge and experience that this centre has generated means that the North East cluster has a relatively strong foundation across supply chain stages and has potential to grow localised cluster capabilities as the industry expands.

In addition to the ORE Catapult, the cluster also hosts a number of higher education institutions and research centres that contribute to the development

[144] Cambridge Econometrics (2020). Research Study into the North East Offshore Wind Supply Chain.

of the sector's knowledge base. Newcastle University School of Electrical and Electronic Engineering is involved in research into several aspects of offshore renewable power generation (wind and wave). Its Design Unit based at the university specialises in the design of gears and development of mechanical power transmission systems. Also associated with the university is the National Centre for Energy Systems Integration (CESI) - funded by EPSRC and Siemens. It focuses on holistic modelling, simulation and optimisation, integrated energy systems research, and future energy systems planning. The Neptune National Centre for Subsea and Offshore Engineering is a new £7 million research centre with world-leading capability in hyperbaric testing and autonomous robots for the subsea sector. The School of Marine Science and Technology is one of the largest and broadest based marine schools of its kind with expertise in marine engineering, coastal management, small craft tech, novel blade and turbine design, foundation design and scouring, power take-off systems, control for marine renewable devices, advanced coastal monitoring and fault diagnosis. The Sir Joseph Swan Centre for Energy Research also engages with the offshore wind sector in its agenda to address the challenges of energy security, energy efficiency, waste reduction, de-carbonisation. Nearby, Durham University, also has several notable research and training programs. Its Energy Institute (DEI) has a wide range of research expertise in areas of science and engineering related to the wind sector but also focuses on societal aspects of energy technology. It also has strategic partnerships with Danish Oil & Natural Gas and BP, among others. Durham's Centre for Earth Sciences focuses on condition monitoring, reliability analysis, large onshore and offshore wind, subsea ploughing for cable installation and foundation solutions in intermediate water depths.

These universities and centres are involved in several pan-UK offshore renewables and wind research networks. The National Centre for Energy Systems Integration (CESI) located at the University of Newcastle involves partnerships with Siemens and the Universities of Durham, Edinburgh, Heriot-Watt, and Sussex. Durham University is also a partner in Project Aura, which is a collaboration between major companies in the offshore wind industry, leading academic institutions and government and non-governmental organisations to catalyse collaboration and innovation to support the sector's growth.[145]

With this combination of sectoral structure and innovation assets this cluster has decent strengths across the innovation process. The concentration of academic research and participation in research networks demonstrates strong localised capabilities in knowledge creation. ORE's expertise in testing products to bring to market speaks to capacity on the value creation part of the innovation process. Additionally, the SMEs involved in the engineering, balance of plant, and O&M stages of the supply chain have been described as quite innovative - although many of these did not focus exclusively on the offshore wind sector but are also (or were originally) involved in the oil and gas industry. Indeed, the high degree of relatedness between technologies involved in oil and gas and offshore wind has proved a valuable source of innovation and commercialisation and is evidence of a degree of innovation diffusion in the cluster. Several commentators noted that the most obvious

[145] Although this project's regional development aims focus more on Humber.

sources of innovation in the sector were coming from outside of the sector, from fields such as robotics, software engineering, advanced materials, and AI.

Overall, this is a cluster that is in the process of evolving - an evolution that will likely accelerate if green energy remains central to Government's (recovery) agenda. The high profile development of the Dogger Bank Wind Farm - currently the world's largest - is expected to see O&M facilities located in the Tyneside area along with associated OEM engineering shops. Cluster leaders hope that the arrival of these large players will have knock on effects through the supply chain and especially on increasing the number and competitiveness of SMEs in the area. Effective cluster planning and foresight will help position the region to leverage these expected investments to grow the industry and maximise its contribution to regional economic development.

Critical pathways

While the cluster is well-positioned to capitalise on projected growth and investment, discussions with cluster stakeholders suggest several opportunities to strengthen the impact of the sector in the region and the innovation process. Here it is appropriate to reiterate that these conclusions are based on a small sample of interviews and so are best interpreted as areas where stakeholder *perceive* weaker links in the logic map. Also, we have opted to focus on a selection of the issues that came up most frequently rather than providing a broad analysis.

Unusually, one of the drivers with the most potential to impact the development in this cluster is one of its core strengths - the knowledge base. In particular, stakeholders perceived a weakness in the link between knowledge creation and commercialisation phases of innovation, which manifests in two ways. First, there is an opportunity to better connect the knowledge generated in academic institutions to firms (particularly SMEs) and other vectors for commercialisation in the region. Secondly, much innovation and commercialisation in components and earlier stages of the supply chain happens outside of the region and significant barriers exist to knowledge flow and integration processes.

In our discussion of cluster assets (above) we highlighted the depth of academic research in the region, particularly concentrated in the research centres based at the University of Newcastle and University of Durham, which engage in knowledge creation across the full range of supply chain stages. The research centres and programmes represent significant investments and are, in many cases, world-leading in their areas of specialisation. These centres promote high-profile partnerships with large firms. For instance, Siemens is the lead industry partner of CESI. The Neptune National Centre for Subsea and Offshore Engineering has close partnerships with GE and Bridon-Bekaert. DEI at Durham collaborates with Dutch Oil & Natural Gas and BP. While these links between universities and industries appear to be well-established there is a sense that SMEs in the region are less connected to these knowledge centres. While this research precludes a deep dive into the technology transfer mechanisms of higher education and public research organisations in the region, stakeholders mentioned that commercialisation and spinouts were relatively rare[146] and not always located in the Tyneside/Blyth area.

Another strand of the knowledge transfer and commercialisation story in the offshore wind sector relates to technology transfer and knowledge integration between firms and across stages of the supply chain. The North East offshore wind cluster concentrates activities particularly around engineering, O&M, and balance of plant stages. Many of these activities happen in the latter stages of the process and in areas where locating close to the projects in development is essential. This pattern of localisation makes sense and is a common genesis of industrial clusters. However, it appears as though firms involved in other phases of the supply chain - notably in designing and producing technologies that eventually make their way into offshore wind hardware or systems - are much more dispersed. The ORE Catapult, for instance, reports working with SMEs from around the country to test their designs and broker connections with OEMs.

While ideally a mature cluster would include a balance of firms from across the supply chain a more dispersed model is not problematic as long as appropriate and effective pipelines of knowledge and technology transfer exist to integrate externally-generated innovations into the more localised innovation process. ORE is one such vector - it is well-positioned to connect firms using its facilities with others in the region - but it is unclear whether there are any others. However useful the ORE pipeline is for knowledge exchange, technology integration, and commercialisation for those firms and the regional economy its clients are (typically) sourced from the pool of firms that are supported by Innovate UK funding, which suggests that there may be many others not aware of or engaged in these programmes. Interestingly, ORE and its facilities act as a powerful magnet and firms have signalled an intention to relocate to take advantage of its expertise and a deeper connection to the regional ecosystem. However, this rarely happens as the small firms are frequently victims of the "valley of death" syndrome whereby innovative firms successful in securing initial rounds of public funding (such as Innovate UK support) fail to attract subsequent rounds of support to bring their innovations to market. Thus, the sector (and the region), are faced with the twin challenges of how to connect a dispersed knowledge space and the fact that innovators often evaporate before commercialisation or dissemination take place.

Ultimately, in both cases, the primary issue is not one of supply of knowledge but of *flow*. This suggests that the answer lies in more aggressively developing interaction across networks - both internally and externally. Cluster foresight exercises should also explore the effectiveness of national and regional support structures, particularly those aimed at commercialisation, converting early-stage innovations into offerings with market potential, and bridging the valley of death to expand the SME ecosystem.

The preceding discussion highlights some of the defining characteristics of the offshore wind sector in the UK:

- The majority of activity is concentrated in a few places that are accessible to offshore projects;

[146] At least in the offshore wind sector. Oil and gas spinouts may be more common.

- Very little turbine manufacturing takes place in the UK;
- Expertise in balance of plant and O&M stages of the supply chain tend to be concentrated;
- Other phases of the supply chain - i.e. project development, turbine component design, etc. - tend to be more decentralised;
- The ecosystem is characterised by a few large foreign-based OEMs and many SMEs.

The result is that the national offshore wind ecosystem has relatively few clusters (you can't do it just anywhere) and that, for the most part, the types of activities that are concentrated tend to be fairly similar. In other words, clusters around the country perform similar functions rather than being identifiably located at different stages of the supply chain. Where these clusters differ most substantially is in the types of industries that they are co-located with.

These broad sectoral and cluster characteristics suggest that other clusters likely experience some of the same issues in their innovation processes as the North East node in the ecosystem. Namely, in accessing and diffusing innovations from outside of their immediate regions and engaging with firms dispersed across the country with potential to contribute to the design and component parts of the supply chain. Our research indicates that there are some links between clusters around the country but that there might be considerable scope for developing them further. For instance, ORE has offices and officers located in other clusters from Scotland to Bristol and several national industry associations exist. However, the stakeholders we consulted rarely mentioned connections outside of the immediate region and when they did, as in the case of the North East, focused on the closest proximity clusters in the East such as Humberside and Scottish nodes in Aberdeen, Glasgow, and Edinburgh. Interestingly, while some highlighted evolving links with outfits in Sheffield (particularly around generator and drive technology), links further west with Liverpool seemed much weaker. From the perspective of development in the NP11, in this sector at least, it appears as though there is considerable scope to strengthen pan-Northern linkages at institutional and industrial scales and around support structures.

Analysis

Overall, the prospects for the North East (Tyneside - Blyth) offshore wind cluster look bright. With the sector deal, the likely endurance of sustainability as a theme in industrial policy, and the scale of offshore projects set to come online growth in this sector, and in the region, seems assured. While COVID-19 has introduced many unknowns, this sector appears to be no more affected than others around the country and supply chain disruptions and investment contractions have not (yet) been massive or crippling.[147]

Yet the preceding analysis notes some disconnects in the cluster's innovation process that might be suitable targets for further research and discussion at the cluster scale and possible policy action by TfN and its partners in the North. Enhancing networks between academic research centres, public

[147] Rae, E. (2020). "COVID-19 and impacts on global wind supply chain." https://gwec.net/covid-19-and-impacts-on-global-wind-supply-chains/ 2020.m

research organisations, and local firms would increase knowledge flows and accessibility to rich and world-leading knowledge bases. Developing stronger networks across the North could also increase knowledge exchange between centres of excellence on each coast. Stronger external networks could also help identify and connect firms involved in various parts of the supply chain in other parts of the country locate users and markets in the cluster. Some thought might also be given to how to effectively attract those firms to locate in the North East to embed them more firmly in the cluster's ecosystem. One route to this might involve policy advocacy for more effective programmes to sustain firms through the valley of death or the development of regional or cluster-specific initiatives.

7.5 North West Chemical and Process Sector Cluster

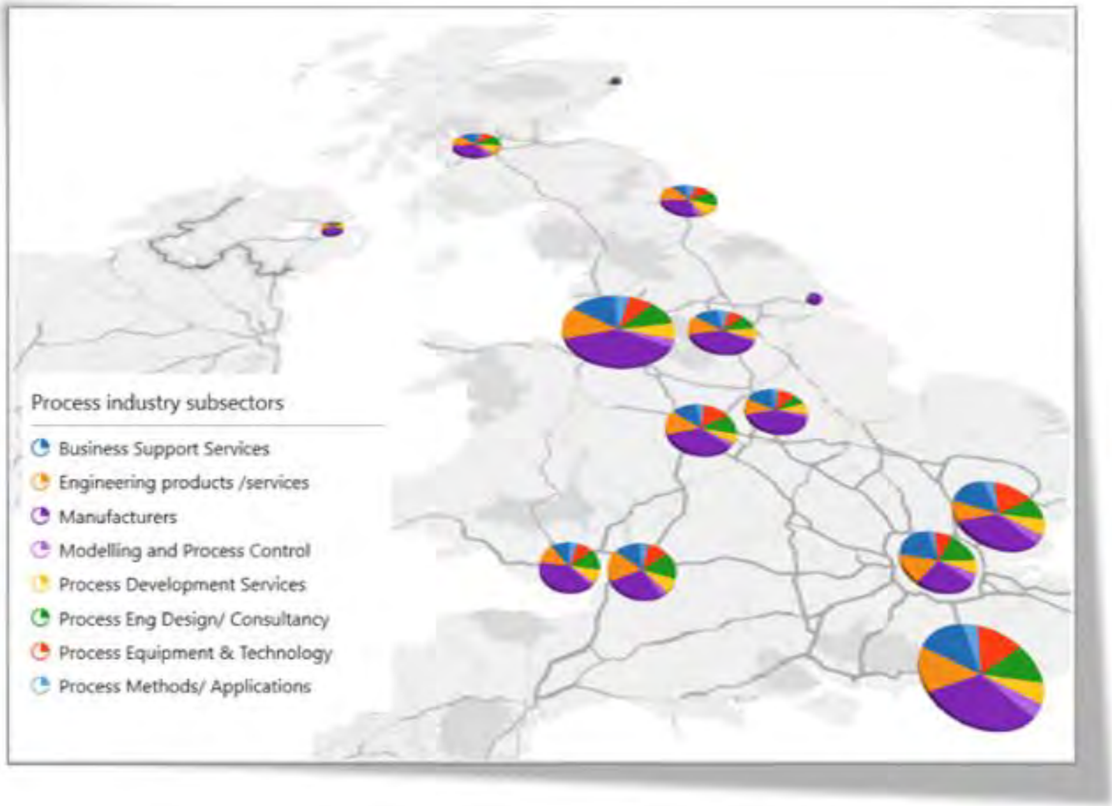
The Chemicals and Process sector remains crucially important to the UK economy. Here we follow the 2018 Science and Innovation Audit (SIA) for this sector in the North in defining it as "the range of industries in which raw materials are processed through chemical conversions to give finished products, where the products and raw materials differ from one another as a result of undergoing one or more chemical reactions during the manufacturing process".[148] According to this report, the 'upstream' chemical producing industries in the UK have a GVA of just over £20 billion (around 10% of total manufacturing output), and employment of 140,000 (with a very high GVA per employee of £144,000). It also supports a much larger set of 'downstream' chemical using industries – aerospace, agriculture, consumer products, construction, and automotive.

Figure 7.5.1[149] shows the sub-national distribution of Process Manufacturing activity (with the same categories of regions as for the other two cases covered in this report) using data on the locations of organisations extracted from an online directory and mapping tool developed by the Knowledge Transfer Network. This includes manufacturing companies in different sub-industries, but also supporting organisations (e.g. engineering services, chemical process services, specialist equipment suppliers, more general business support services) that are also important parts of wider chemical and process clusters. The biggest regional concentration of this activity on this map is the North West of England. Around 37% of these organisations in the North West are manufacturers (compared to 33% across the whole of the UK) and therefore 63% are in the other supporting services.

[148] Hammond, T. and Wilson, K. (2018). Northern Powerhouse: Chemical & Process Sector. Science and Innovation Audit: Full Report, Department for Business, Energy & Industrial Strategy. page 1.

[149] KTN Process Manufacturing UK Landscape Map, https://pmfg.ktnlandscapes.com/

Figure 7.5.1: Map of concentrations of Process Manufacturing in the UK



Source: KTN Process Manufacturing UK Landscape Map

A recognised sub-regional concentration in the North West covers the Local Enterprise areas for Liverpool City Region and Cheshire and Warrington. This is one of three Northern clusters identified in the SIA mentioned above, alongside Tees Valley/County Durham and the Humber. Some headline figures for these clusters from the report are given in Table 7.2.1.[150] This shows the Liverpool/Cheshire cluster has a lower location quotient compared to the other two (indicating the industry accounts for a lower share of overall employment in the region), but includes a higher number of establishments and accounts for a markedly higher level of GVA overall and by employee. The identification of this cluster centred on Liverpool City Region and Cheshire and Warrington reflects the presence of key industrial assets in these locations (see below). However, our review of the evidence in the appendices underpinning the SIA, the KTN landscape mapping tool referred to above, and other sources[151], also highlights substantial chemical and processing activity taking place in the neighbouring LEP area of Greater Manchester. A key cluster support organisation, Chemicals Northwest, also operates at the regional scale. In the rest of this section we will therefore consider a wider geography that includes these three co-located LEPs that comprise the economic centre of the North West region.

[150] Hammond, T. and Wilson, K. (2018). Northern Powerhouse: Chemical & Process Sector. Science and Innovation Audit: Full Report, Department for Business, Energy & Industrial Strategy. page 4.

[151] For instance, NIESR (2017) Industrial Clusters in England, BEIS Research Paper Number 4.

Table 7.5.1: Attributes of Chemical and Process clusters in the North of England

Cluster	Total GVA	GVA per employee	Location Quotient	Number of establishments
Liverpool/Cheshire	£60,196m	£449,000	3.0	373
Tees Valley and Durham	£21,312m	£154,000	3.7	163
Humber	£18,378m	£215,000	4.1	192

Source: Hammond and Wilson (2018).

As discussed below, this North West cluster encompasses historical and current specialisations in different chemical producing industries (and supporting services). It also provides key inputs to many other significant manufacturing industries in the North West and UK more widely (including aerospace, automotive, and consumer goods). The relatively dispersed and diverse nature of chemicals and process activity in the North West meant that one person consulted for this project felt that, despite its collective size and economic impact, the sector did not have as strong an identity as the more focused cluster that exists around Teesside in the North East of England. In the North West, chemicals and processing could therefore be considered an example of a 'hidden cluster' that may not be as clear to policymakers as it cuts across the boundaries of many different industries.[152]

Specialisation and main cluster assets

The North West chemicals and process cluster has important research assets in different parts of the region. In terms of universities, the two major research-intensive institutions are the University of Liverpool and University of Manchester. Both of these have strengths in chemistry and related fields that are relevant to the sector. The University of Liverpool in particular is world-leading in Materials Chemistry that a Science and Innovation Audit for the Liverpool City Region identifies as underpinning higher-value economic activities than commodity chemical production.[153] This strength was reinforced by a major investment in an industry-led research institute - the Materials Innovation Factory - in partnership with Unilever. This forms part of the Henry Royce Institute, a national research institute for advanced materials, that has multiple university partners across the country, but a central hub based in the University of Manchester. Beyond these leading research-intensive institutions, the University of Chester was identified by those consulted as an important actor in the regional chemicals and process ecosystem. This university has established a science park (including its Faculty of Science and Engineering) on a site in Thornton that until 2014 was home to Shell's main research and development base in the UK. Another important site where leading laboratory facilities and business are located at the heart of the North West cluster is the Sci-Tech Daresbury campus. In the wider North West region, the University of Lancaster was also identified as having significant

[152] Williams, N., Brooks, C. and Vorley, T. (2016). Hidden clusters: the articulation of agglomeration in City Regions, *Environment and Planning C: Government and Policy*, 34, (8), 1776-1792.

[153] Liverpool City Region (2017), Liverpool City Region +: A Science and Innovation Audit – Main Report, Liverpool City Region Local Enterprise Partnership, Liverpool. page 31.

expertise in chemical regulations and helping companies in the cluster adapt to changes involved with complying to the EU REACH legislation.

As mentioned above, the North West chemicals and process cluster contains a number of industrial strengths that are distributed across different locations. A key centre remains Runcorn on the River Mersey in Cheshire. This was the former home of a major Imperial Chemical Industries (ICI) facility until the early 2000s. When this closed, its manufacturing and laboratory assets were acquired by other companies (such as Ineos) who continue to produce chlorine related products in the area. Other industrial strengths in the region include, for example, pharmaceutical manufacturing. This includes a large AstraZeneca manufacturing site in Macclesfield in Cheshire. The SIA for the sector in the North of England, notes that Liverpool and Cheshire have concentrations in inorganic basic chemicals and pharmaceutical preparations, and (compared to Tees Valley/Durham and Humber) “the largest companies by scale (and consequently a greater number of higher value adding functions)”[154]. At the same time, however, the cluster is still largely comprised of smaller and medium enterprises. Many of these produce chemicals for other companies as part of supply chains. For these companies, innovation is often restricted to what one consultee described as ‘niche’ areas in order to solve problems that their larger customers will pass down to them. Accordingly these medium sized companies will often have some research capabilities in in-house laboratories and scientifically trained staff that they can use to add value to their products. The consultations also highlighted some specific areas of more radical innovation that are emerging in the sector. For example, these may be focused on reducing the environmental impact of the sector through more sustainable uses of chemical materials or lower carbon energy sources. A significant opportunity being pursued by a consortium of partners in the region is to make the North West a leading centre for the development of decarbonised, hydrogen-based energy.[155]

Notwithstanding these developments, there is a general recognition (reinforced by the SIA exercise) that if the sector as a whole is to remain internationally competitive, it needs to use research and innovation to help more of its companies move up value chains into new markets. A recent industrial strategy sector deal for chemistry-related industries also highlights the need for ‘disruptive innovation’ to drive growth through the development of new products and processes (particularly with a link to the strategy’s clean growth theme).[156] This need will become more pressing if the UK leaves the EU Customs Union without a deal at the end of 2020 and tariffs are applied to low margin chemical products exported by companies in the North West of England. The next section will examine some of the systemic innovation challenges that the cluster will have to overcome if it is to successfully undergo this type of transformative process.

Critical pathways

A SWOT analysis included in the SIA for the Chemicals and Process Sector in the Northern Powerhouse highlighted a number of general challenges to the

[154] Hammond, T. and Wilson, K. (2018). Northern Powerhouse: Chemical & Process Sector. Science and Innovation Audit: Full Report, Department for Business, Energy & Industrial Strategy. page 4.

[155] See http://www.nwhydrogenalliance.co.uk/ [accessed 22/06/20]

[156] Chemistry Council (2019) The Chemistry Council Sector Deal: Sustainable Innovation for a Better World.

functioning of systemic innovation processes. The weaknesses identified in this exercise included:

- Mature sector with high costs of entry to new start-ups;
- Limited investment in research and development, particularly amongst mid-tier domestically owned companies;
- Business R,D&I (research, development, and innovation) conducted outside the region;
- Disconnect between research base and technology transfer functions.[157]

The consultations carried out for this project largely reinforced these points and helped to understand some of the factors underlying their form within the sector. The rest of this section will explore these through the lens of the critical pathways framework developed for this study.

A key enabler of innovation in the logic map are *Business Base Characteristics*. These characteristics (including size, age, ownership, structure, supply chain position, etc.) are fundamental in defining the scope for companies to engage in innovation internally or through collaboration with external organisations. The size and diversity of the chemicals and process sector in the North West means that robust generalisations about its constituent businesses are hard to make. However, some relatively common features were highlighted by those consulted for this project. Principal amongst these is the maturity of many of the companies that have been producing chemicals or providing support services over a period of decades. This means they have built up competencies and knowledge so that they are highly competitive in the markets and production processes in which they specialise, but may have less flexibility to engage in forms of innovation that will help them move into new markets. In particular, this characteristic is likely to impact on levels of new technology *adoption* within the innovation process.

These business base characteristics can be traced in the logic map through several of the innovation drivers. For instance, mature companies with established routines are less likely to have an *innovation culture* that encourages risk-taking and diversification into new areas. This tendency may be reinforced by a prioritisation of many companies in remaining competitive by increasing efficiency, which leaves little structural redundancy or excess 'slack' resources in the organisation that could be allocated towards experimentation.[158] Innovation in the industry is more likely to be an incremental process driven by problem solving and finding solutions to customer needs. The uncertain business environment currently facing these companies due to Brexit and the COVID 19 pandemic (see above) may also reduce their capacity to invest in new technologies and processes. Supporting these traditional companies to be more risk-taking could be a role for innovation policy targeted at the cluster.

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[157] Hammond, T. and Wilson, K. (2018). Northern Powerhouse: Chemical & Process Sector. Science and Innovation Audit: Full Report, Department for Business, Energy & Industrial Strategy. page 9.

[158] Staber, U. and Sydow, J. (2002). Organizational adaptive capacity: a structuration perspective, Journal of Management Inquiry, 11,(4), 408-424.

The maturity of companies in the sector also shapes the human capital profile of the cluster. A feature commented on by consultees was that the current workforce in the region is highly skilled and experienced in, for instance, operating specialist equipment effectively. It is, however, well-recognised that the average age of this workforce is now high, and there is a pressing need to bring younger people into the industry. It is projected that almost forty percent of the workforce in process manufacturing is over 45 years old.[159] This task of replacing skilled workers is made more challenging by the difficulties of attracting university graduates who often, even when they are trained in chemistry or engineering related subjects, prefer to enter other less traditional or high-paying industries. One stakeholder noted that the withdrawal of ICI and Shell from the region may have contributed to this problem, as these larger corporations had strong graduate recruitment and training programmes that were previously an important route for many young people into the sector. The medium sized companies that have tended to replace them do not have the capacity to replicate these programmes on their own, so may need to participate in cross-organisation initiatives to expand the flow of graduates into the cluster. It should be noted that there are already programmes in place in the region that are targeted at addressing this issue around future skills in the industry. This is, for instance, the remit of a North West-based support organisation called Cogent Skills that focuses on vocational education and apprenticeship standards in science-based industries. The Chemical Engineering degree course offered by the University of Chester was also mentioned as being especially oriented towards preparing students for a career in the chemicals and process sector.

Finally, business base characteristics are a major influence on the industry *knowledge base* as a driver of innovation. As outlined above, the established companies and workforce in the cluster are a source of considerable technical expertise. This embedded knowledge base is also supported by the research and testing capabilities that many companies with laboratory facilities and staff possess. However, as highlighted in the sector weaknesses identified in the SIA, the small and medium size of companies in the industry, and their ownership as part of larger corporate groups with R&D functions based elsewhere, can limit the potential for this knowledge base to support novel, path-breaking innovations. Similarly, research and consultancy relationships with regional universities do seem to be common, but these networks may not be extensive enough to translate into widespread incidences of new scientific knowledge becoming effectively commercialised by companies within the cluster. This could be addressed by a strengthening of technology transfer processes involving universities, but will also be constrained by the business base characteristics that restrict the absorptive capacity of companies to assimilate and apply this knowledge within their existing production. University spin-outs do exist in the cluster (for instance, Nanoco from the University of Manchester), but this is a mechanism that could be supported to increase the presence of newer, science-focused companies.

[159] https://www.cogentskills.com/about/our-industries/ [accessed 22/06/20]

Function in and connection with the national innovation ecosystem

The North West cluster is closely integrated into a wider chemicals & process sector in the UK. Consultees for this project identified the other main centres in the industry as the two other northern clusters identified above, Teesside and the Humber, and Grangemouth in Scotland. These centres have strong connectivity through sea routes (they are all on the coast) and an infrastructure of pipelines between different refineries. Company supply chains also connect these different clusters in the UK. As noted above, many other industries are supplied with chemical products, but consultees noted that the largest customer for the chemicals industry is the chemicals industry itself.

Companies in the North West chemicals and process sector also have knowledge networks that reach beyond its regional cluster. While there are strong university assets in the region (see above), larger companies in particular may work with leading universities throughout the country to access specialist knowledge. The North West universities are themselves part of wider collaborative networks, such as the Henry Royce Institute mentioned above that includes the universities of Manchester and Liverpool. A key national asset for the sector is the Centre for Process Innovation (CPI) primarily located in Teesside and County Durham. This major technology and innovation centre is now part of the High Value Manufacturing Catapult network supported by the UK government, and therefore has a mission to work with universities and companies across the country (including the North West).

Analysis

The North West Chemicals and Process cluster is a main centre of activity in a large and strategically important sector for the UK economy. In comparison to the emerging offshore wind energy and digital health sector, it is a much older set of industries that have a strong heritage in the North West. Accordingly, companies in the sector are able to draw on specialist knowledge and organisational routines that have been developed over time to support their competitiveness. It is, however, recognised that to remain internationally competitive the cluster (and wider industry in the UK) needs to move up value chains driven by more radical, research-supported innovation. In this context, the strengths mentioned above can become a barrier to companies adopting the new technologies or processes that are needed for new knowledge deriving from research and development activities to be widely disseminated and commercialised within industry. The analysis above identifies issues around the research and development capacity, innovation culture, and ageing workforce in the sector that may affect the successful adoption of the innovations that are needed for established companies to move into new markets. These issues show the importance of business base characteristics as an enabler of innovation.

Despite these challenges, opportunities for innovation do exist for established and newer companies, often driven by new requirements for environmental sustainability. There are also scientific strengths in universities and other centres in the North West and UK more widely that companies may be able to draw on more extensively than they currently do to help support the future transformation of the cluster.

7.6 Synthesis of findings

These case studies provide insights into a variety of different types of clusters at different stages of development, maturity, and with different market and industrial profiles. Exploring such a diversity of sectors allows us to demonstrate the effectiveness of this approach for cluster evaluation and query a range of economic development experiences across the North. Beyond demonstrating the value of the logic chain to development analysis, our primary aim was to highlight areas of commonality between the cases to suggest potential policy directions to drive innovation and growth across the region.

All three clusters have strong foundations in their geographies and are anchored by strong public investment and/or large and internationally significant firms. The Leeds digital health cluster emerged around NHS assets that are a built-in market for innovations in this segment of the knowledge space. The offshore wind industry in the North East benefits from the ORE Catapult, which functions as an international magnet for testing the latest technologies and as a powerful national and global knowledge pipeline. The mature oil and gas industry in the area also contributes to the innovation performance and potential of the cluster and an established higher education programmes and labs are engaged in world-leading research. The chemical and process industries in the North West boasts a relatively large number of multinationals and a well-developed knowledge infrastructure in higher education and public research organisations. All of the clusters have relatively robust talent pools - although the aging of the chemical manufacturing workforce may pose longer term issues for growth. In sum, these clusters have a lot of the necessary raw material to drive innovation. Unsurprisingly, the greatest opportunities to improve performance across the innovation process centre on how to more effectively leverage local capacity and access external assets.

Arguably, all three clusters suffer from the same issues. Viewed from the outside, they appear to perform well on (aspects of) all three categories of metrics in the innovation process. However, the links between those could be more effective. For instance, all have impressive knowledge creation capacity but they struggle to capture as much value as exists from that knowledge base. In Leeds, small and innovative firms have solutions but struggle to access the largest and most influential markets due to barriers related to public procurement and high market-readiness requirements. In the North East offshore wind sector, the research produced in public universities may be being commercialised elsewhere while many SME innovations fail to reach market due to valley of death firm failures. In the chemicals and process industry in the North West high barriers to entry combined with the dominance of large firms with insular innovation practices may be choking knowledge circulation and potentially reducing commercialisation.

The value creation to diffusion links also appears to be weak across all three clusters. While evidence is less robust on this metric, weak knowledge circulation may be having the effect of reducing the adoption of locally-generated innovations. In the digital health industry this manifests as a fragmented market, with numerous independently operating networks and support organisations throughout the North. The offshore wind sector appears to be relatively active in adopting solutions from other industries and adapting new technologies. However, many of these innovations originate from outside of the cluster, from parts of the innovation ecosystem that are not well-integrated with the local industry, and the degree to which innovations are diffusing locally is unclear. The chemicals industry in the North West exhibits relatively strong knowledge diffusion networks but appears to face a similar problem to the offshore wind sector to the extent that large manufacturers regard their processes as proprietary and a lot of key research occurs in branches of multinationals located elsewhere. Ultimately, while these clusters may perform well on the individual metrics these are the product of the activities of firms that *were able to* reach markets and *were able to* access and adopt often externally generated innovations. Our research suggests that there may be a substantial number of firms - or ideas - that failed to reach market or learn from and adopt locally generated innovations. Capturing this unrealised potential represents a significant opportunity for future cluster development.

In each case, the causes of these weak links are slightly different - the drivers and enablers involved in creating these conditions vary - and these are elaborated in more detail in the case study sections. However, we identified some commonalities in the critical paths particularly engaging culture and network drivers and the business base characteristics enabler.

The gaps in knowledge commercialisation and innovation diffusion for some actors in the cluster stems in large part from weaknesses in and engagement with local and external networks and barriers related to innovation culture. While it would be a gross oversimplification to state that cluster networks are weak across the board in all three cases, there are clearly gaps with SMEs, in particular, having more difficulty accessing and participating in these assets. For instance, stakeholders reported that digital health firms in Leeds faced difficulties in accessing clients and other firms in local networks. In offshore wind, networks between universities and firms, particularly SMEs, could be more developed and between firms both in the region and outside of the region at different points in the supply chain. In chemical industries, existing university-industry partnerships and collaborations could be extended

Innovation cultures could also be more tolerant of risk and adopt more open innovation models. Stakeholders in both chemical and offshore wind sectors remarked that firm business models were built around proprietary technologies and that interfirm partnerships and collaborations were not common as a result. In the digital health sector, knowledge and innovation is transmitted in large measure through the networking partnerships and the digital sector is known for strong cultures of innovation. However, because of the highly sensitive nature of the data handled by health information systems and the fact that the largest clients are government agencies that require market-tested technologies, this sector is also fairly risk-averse, resulting in a limited ability to leverage the entire digital capabilities in the religion, found across the information technology and financial sectors.

All three clusters have interestingly similar business base characteristics, which play an important role in shaping the challenges and opportunities in each sector and place. These ecosystems are characterised by a small number of large and established, often foreign, firms and a plurality of domestic SMEs. In the offshore wind sector and chemicals industries these are large multinationals. In the digital health information systems space large domestic firms are well entrenched. This structure is a double-edged sword in all cases - these large firms anchor and draw on, and hence stimulate, local firms but they can also crowd out other entrants, dominate knowledge transfer partnerships, suck up talent, and leverage local knowledge for commercial activities elsewhere in their pipelines. Furthermore, with their investment decisions and market clout they also have a large influence on the future development of the cluster. Firm failure, relocation, or decisions to invest elsewhere have meaningful impacts on the prospects of the sector in that region.

The balance of firms that are SMEs benefit from these anchor firms but are also important to maintaining a vibrant and resilient ecosystem. Small digital health firms in Leeds report difficulties building reputations and market testing their innovations to build confidence for clients. In the North East, the ORE Catapult testing and validation facility was set up to bridge a similar gap for all firms in an industry that requires robust stress testing before committing billions in investment at scale. While that testing capacity exists, access to funding and markets remains a problem for SMEs. In the chemicals and processing cluster in the North West, SMEs are often part of supply chains that are dominated by larger firms. This position leaves opportunities for them to innovate within specific niches, but may restrict the scope within their business models to engage in other higher-value markets. The most appropriate form of support for each of these clusters varies but these cases suggest that the SMEs across these sectors could use assistance accessing funding, innovations, and markets. Being better plugged into local networks would be an asset in all of these cases.

It is important to note that however important local networks are to the innovation process, they are not the only source of the clients, funding, or innovations that firms can leverage to support their commercial activities. These clusters do not exist in isolation and are embedded in broader national ecosystems and international markets. We contend that cluster development should acknowledge local specialisations, functions in those broader markets and networks, and the impact of external regulatory and trade environments. Furthermore, the more decision makers grasp the relational aspect of clusters the more effectively they can develop the external links and strategies to support local development. Actors in each of these clusters rely to varying extents, on external sources of innovation, funding, and support. However, it is also clear that they could be much more effective in leveraging assets available across their national sectoral ecosystems - and particularly those located in other areas of the North. Stakeholders in most cases noted only sporadic and usually ad hoc relationships across jurisdictional boundaries in the North despite the presence of significant related centres of excellence.[160] The main exception was the chemicals industry in which stakeholders reported that larger firms engaged in knowledge partnerships with universities around the country. While competition may provide a partial explanation, strengthening ties between clusters across the North represents a significant

[160] Note that these interorganisational relationships are generally better developed between academic and public research organisations. However, there are often spatial biases in these as well.

opportunity to better engage with existing regional assets to support localised development.

8 Policy Implications

8.1 Introduction

This study has provided insights into the innovation process, how it functions across the UK and in the North particularly, and what the role of TfN and of other pan-Northern bodies could be in leveraging those insights in pursuit of regional development objectives. In the process, we produced (1) a logic map of how factors interact to drive and enable the innovation process, derived from the latest academic literature; (2) an evaluation of how LEPs across the country perform against a wide range of core indicators; (3) based on these, a series of insights about the relationship between space, place, and innovation that can be used as a basis to formulate targeted investment policy; and (4) a methodology for evaluating innovation ecosystem assets at different geographical scales and sensitive to both the systemic and relational dimensions of regional development.

Summary of project objectives

The project addresses the wider question: what factors can meaningfully influence productivity growth in the North? Building on this we generated a series of sub-questions, as stated in Chapter 1 that shaped our approach to the issue, they were:

- How does innovation happen within a geography and how does that knowledge and technology diffuse throughout the economy?
- What are the drivers, enablers, and barriers to these processes?
- What do key indicators tell us about how Northern LEPs perform relative to each other and the rest of the UK?
- What questions do these results raise and how might they be tested to deepen our understanding of the North's innovation landscape?
- How do these results align with or diverge from those of previous studies in this area?

A major contribution of this research is its consideration of the way in which innovation takes place across geographical space and its explicit interest in how the innovation process is shaped by the knowledge spaces in which it is embedded. Adopting a systems-inspired approach - in which we conceptualise the innovation ecosystem as a complex system - forces us to consider innovation in a new light.

Firstly, it shifts our mode of inquiry from seeking explanations through narrow thematic or sectoral silos and encourages an understanding of innovation as the product of interactions and interdependencies between drivers, enablers, and outcomes. We apply this perspective most obviously in the development of the logic map and the elaboration of the links between elements. Secondly, a systems-inspired approach underpins our exploration of sectoral and technological strengths, and their relative concentrations across the UK. In conceptualising places in terms of knowledge spaces, we can seek *connections* (or relatedness) between sources of innovation, query their relationships, and begin to predict future outcomes. Finally, our complex systems lens suggests a holistic approach to understanding the regional economy. That is, we contend that the Northern economy is more than just the sum of the economic activities that happen within its geographical units. Innovation and prosperity do not stop at the boundaries of each LEP. Again, this encourages us to look for pan-Northern dynamics and opportunities, even as we employ the LEP structure as a spatial frame of reference.

This approach means that we're looking for different things and seeking to understand dynamics instead of outcomes. This enables us to trace and triangulate, for example, the combinations of drivers and enablers most likely to support the innovation process (critical pathways), and to explore the combinations of technologies and sectors that represent the most promising sources of next generation innovation. In the next section, we summarise the most relevant findings from those investigations before turning to policy implications.

8.2 Summary of findings

The innovation process and logic map

The logic map conceptualises innovation as a process and not just as an outcome. In our map, the innovation process comprises three phases through which multiple paths are possible:

4 **Knowledge creation:** where ideas are generated through research or processes of serendipitous discovery.

5 **Value creation:** where ideas are either implemented internally within firms (e.g. as part of their production processes), or commercialised through any number of channels.

6 **Diffusion:** involves the broader adoption of the innovation throughout the economy. This has two phases – one in which the innovation is disseminated (pushed) to markets and through networks and a second where that innovation is adopted (pulled) by entities for their own implementation or research/discovery purposes.

This is a dynamic and not necessarily linear process; each of the links in the innovation process has the potential to stimulate activity at other phases. Innovation policy should be careful of prioritising one phase over others. Furthermore, this conceptualisation helps to highlight that the links and pathways between phases are as important as measures of performance at each stage. In other words, we should think about the effectiveness of pathways and give some consideration to what kinds of attrition might be occurring along the way (and why).

Furthermore, dividing the innovation process up into three interlinked stages allows us to begin to identify relative strengths, weaknesses, and mismatches across the entire innovation chain, within different spatial areas. For example, whilst one geography may excel at creating new knowledge in a particular technology or domain, it may perform poorly at implementing or commercialising that knowledge. Understanding how the innovation chain of any given technology functions across space, and where the key linkages are, has the potential to provide clear insights into current weaknesses and opportunities for improvement.

Disaggregating the innovation process into these three stages also allows us to make an important point about the effect of drivers and enablers. Critically, we argue that the combination of drivers and enablers, the nature, and magnitude of their impacts will vary across stages of the innovation process. For example, knowledge bases play obvious and important roles in the knowledge creation process - it is the raw materials from which innovations are constructed. Yet in latter phases - value creation and diffusion - it may equally refer to the knowledge pool that managers will draw from (for instance) in order to prioritise resource allocation and investment decisions. Acknowledging this potential for variation in function and impact of drivers at different stages of the process adds important nuance to what might otherwise be conceptualised as a static relationship.

In many respects the drivers and enablers identified do not differ substantially from what might be found in any textbook on innovation. None of these elements is particularly unusual or surprising. What is novel, however, is how we have conceptualised them as interdependent - as part of a system in which the various elements have influences on one another - instead of as merely inputs that sum to observed outcomes. The connections that we highlight[161] between them may appear complex but in some respects that is the fundamental point. Making the intricacy of these interdependencies explicit can, perhaps counterintuitively, help clarify our understanding of the dynamics at play in a given context. As a conceptual model, this map has value in helping to highlight the importance of understanding these dynamics in any policy decision; for example, a policy to facilitate innovation by improving regional skill levels cannot be considered in isolation from important regional pull factors such as quality of place, connectivity and public research institutes. However, in Chapter 7, we demonstrate that it has even more power in context and can also be applied to map and understand pinch points and critical pathways for intervention in specific geographies (in that instance, clusters).

Evaluating the innovation process in the North

We used the logic map in Chapter 3 to frame our evaluation of innovation performance and the potential of the economy in terms of both drivers and enablers. At this level of analysis, we focused primarily on operationalising and measuring indicators to explore patterns of strengths and opportunities for improvement and did not attempt to fully elaborate the quantitative relationships between logic map elements. Our analysis revealed a number of interesting patterns, summarised in more detail in Chapter 4. We looked at patterns of performance both across the UK, and within the North more closely. The data suggested that an area of central, southern England performs particularly well across a wide range of innovation metrics. This high-performance area does not conform to a specific NUTS1 region but includes all of London and part but not all of four different regions; South East, South West, West Midlands, East of England. This encouraged us to seek lessons that can be learned from both this area and inspires us to think about innovation ecosystems, and high-performance areas, in ways that are not necessarily bound by existing regional geographies.

[161] It is perhaps appropriate to reiterate here that we do not claim that these connections are the only ones or that the understanding depicted in our logic map is comprehensive. While our work was based on a careful review of the literature systems dynamics approaches demand that we acknowledge that these can function in very different ways in different cases and that, in policy, there are no universal laws. That said, we believe that this map is an effective depiction of relationships at this level of conceptual granularity.

Some observations about the characteristics of this high-performance area hold potential insights for the North:

Firstly, proximity to a major world city, and to a secondary degree its surrounding international airports, are of clear benefit. The area benefits from strong involvement with multinational corporations and venture capital. Although much of the innovation activity occurs outside of London, the role of London as a convening and networking hub is clearly crucial. A question that might arise is the extent to which larger cities in the North are able to facilitate innovation in their surrounding areas in the same way.

Although there are a number of cities spread around the South of England, as a whole the area is largely rural or suburban in nature, with a range of smaller, historic cities, and market towns. It could be speculated that the advantage this brings is in the variety of lifestyle offers available to mobile knowledge workers both from the UK and from further afield. Indeed, the data shows that this area is particularly adept at attracting and retaining knowledge workers. There are two implications here for the North; firstly, the importance of generating a high quality of life offer, and secondly, the role that rural areas and smaller historic cities can play in the wider innovation system.

The key to the success of the wider ecosystem is the extent to which different geographic areas are able to both develop their own specialised niche within the whole, and then collaborate and share knowledge (during all stages of the innovation cycle) with neighbouring areas who have complementary specialisations. A network of knowledge generators, implementors, disseminators and adopters is thus created across a wide variety of knowledge domains, and through this process a system-wide related variety is ensured.

Although the southern innovation ecosystem is evidently private sector led, the presence of long-established public institutions is also clearly a factor, not just in the generation of knowledge, but in the attraction and generation of knowledge workers, be these world-leading Universities at Oxford or Cambridge, or other public institutions such as DSTL and GCHQ, evidence of the ability of publicly-funded research to “crowd in” private sector R&I activity over the long-term.

Regional knowledge spaces, technologies, and sectors

In the first of the empirical chapters (Chapter 3) we focused on understanding the current state of knowledge spaces, across the region and for each of the LEPs. This research was centred on the question of what areas does the North specialise in, and how are those specialties distributed (and how are they different) across the region? While previous research has tackled this question, it has typically focused on answering it using employment data. Our approach is novel to the extent that it explores this question through the lens of patent data, which because patents are one manifestation of innovation, we argue gives a more granular understanding of knowledge and value creation in the region. In particular, because this approach highlights innovation output rather than other measures of economic impact (e.g. jobs), it can provide insights into the smaller or nascent sectors that are contributing to regional productivity and identify areas where public support may enable firms to scale or increase investment to optimise impact.

Through our analytical process, we were able to produce technological profiles of the knowledge space of the country, its regions, and each of the 11 Northern LEPs. The analysis of the evolution of the regional knowledge space provides insight into the North's industrial history and reveals some clues about its future. A focus in the 1980s and 90s on technologies related to chemicals and metallurgy, consumer goods, transportation and operations, with some peripheral textiles and paper saw both convergence and deepening by 2015. More recently those central technologies have been joined by increased patenting output in technologies related to physics, electricity, and mechanical engineering, while some of the more traditional technologies (such as textiles and paper) remained relatively peripheral within the overall knowledge space, with limited connections to other domains.

Overall, the Northern knowledge space has seen an increase in density of interactions and clustering, indicating co-occurrence of technologies on patents and demonstrating that there has been significant cross-fertilisation between technologies. The cognitive proximity of some of the technologies in which the North exhibits strength suggests that this type of convergence will likely continue, and should be supported in doing so. A key question that emerges from this research centres on how this knowledge space is likely to evolve and what policy can contribute to directing, accelerating, deepening, and capturing the benefits of recombinant trends, including both the strengthening of existing trends, for example in the emerging physics and electricity cluster, and the addressing of noticeable weaknesses, for example better linking innovation in textiles to other knowledge domains.

This data also revealed some interesting patterns of regional specialisation in comparison with other UK regions. By evaluating the frequency of patents from different classes we observed a typology of both geographical strengths and emerging trends. Within the overall UK knowledge space, the North specialises in patents in the fields of chemistry, materials, textiles and process engineering. The LEPs of the Midlands Engine have relative expertise in heavy industry and engineering; vehicles, metals, pumps and engines. Finally, the southern part of the country is more dominant in physics, electronics and computing. While it will take some time to parse the significance of these patterns and the extent to which these relative specialisations in knowledge space can be leveraged to identify useful complementarities, it does validate the idea that there might be commonalities across regional economies but also challenges the definitions of those regions. Understanding regional economies in this way might provide an opportunity to rethink spatial development strategies in the UK and opens up new ways of thinking about inter-regional synergies and integration.

As identified above, theory suggests that the critical role of geographical sub-areas (such as LEPs) within wider regional innovation ecosystems is to identify and build their specialised role within the wider, more knowledge-diversified regional system, which may or may not strictly conform to the pan-Northern geography. This data presents opportunities for LEPs to (re)consider areas of industrial specialisation and sectors with the greatest growth potential. By tracking and exploring the evolution of their knowledge spaces presented in this way, LEPs would be able to identify local specialisations and technological trajectories and pinpoint technologies and industries with the potential to emerge more significantly as innovation drivers. There is significant scope for more research on how knowledge spaces evolve and why they change as well as to develop analytical tools to more accurately predict areas of potential growth.

Potential for recombinant knowledge production in the knowledge space

While understanding specialisation can help guide development policy, this patent data analysis is most accurately a description of the past. While this can help shape expectations about the future, using this data and some novel methodologies, we can also develop models to help identify previously unknown technological areas with the greatest growth potential. One approach is based on the concept of recombinant knowledge, which posits that some groups of knowledge and artefacts are easier, and more likely, to combine than others. Understanding which types of knowledge, and technologies, are likely to come together in new ways can be a powerful tool to predict sources of innovation. This understanding can, in turn, help target policy efforts to seed and catalyse industrial development.

Our analysis of relatedness in patent data yielded insights along several vectors - namely, place and technology. The potential for innovation of a place can be determined by measuring its levels of technological diversity (entropy) and the similarity between knowledge classes in the pool (relatedness). The logic is that the places that score highly on both measures are likely to have the greatest potential for recombinant knowledge production. That is, they are places characterised by lots of raw material or building blocks for innovation and those blocks are sufficiently similar to one another that they can be effectively combined. In the North, places like Lancashire, Cheshire and Warrington, and Leeds City Region rate highly on recombinant potential. However, it should be noted that there is considerable variation within North, and between LEPs, signalling that some places have more advantages in innovative potential than others.[162]

Additionally, this data can highlight in more detail which combinations of technologies are likely to be the source of innovation. This research looked specifically at existing specialisations or near-specialisations within the North that can be built upon; technologies that occupy specific key points in knowledge networks and that act as conduits between two different technological fields; and technologies that have had a high growth rate within the UK as a whole over the past 15 years, which we use as a reasonable proxy for future growth. While we don’t summarise the specific findings from that analysis here it is clear that there are many potential areas for innovation growth in the North. When cross-referenced with measures of employment density and specialisation (e.g. employment LQ) this provides useful data that LEPs can use to determine their evolving areas of competitive advantage.

Innovation partnerships

Patent data is a useful lens through which to examine innovation performance and potential, but it is important to recognise that this form of commercialisation represents only a fraction of the innovation in an economy. Another question that interested us related to how knowledge was shared, or flows, across the North and to other parts of the country. To better understand who is involved, and in which sectors, in innovation collaborations we could

[162] Note that while these places tend to also be those that score highly on our innovation metrics, there isn’t a perfect correlation. This suggests that more work might be needed to better understand the link between these measures of potential and actual outcomes.

get a better grasp on the extent to which Northern innovators are connected to each other and broader networks. Here we relied on data from Innovate UK funding applications on research collaborations and compared it to our data on patent co-inventors.

This analysis proved interesting and, we think, tells an important story about how knowledge is flowing and being leveraged across the UK. Exploring the inter-LEP patent collaboration showed that co-invention tended to follow regional trends, with the majority of collaborations taking place between organisations in nearby or neighbouring LEP areas – most likely as a result of co-inventors working for the same organisation. A distinct difference between the Greater South East and the rest of the UK is immediately apparent, with a single dense collaboration network covering an area roughly coincident with our “high-performing region” identified above. Organisations in Southern LEP areas collaborate frequently with the majority of their neighbouring LEP areas; seven Southern LEPs had a degree centrality of 6 or above, whereas only one Midlands LEP, D2N2, did; and no Northern LEP area. The North and Midlands innovation ecosystems, on this measure, are less dense than that of the wider South East, with most LEP areas only having strong collaboration links to one or two of their closest neighbours. Formal collaboration doesn’t happen to the same extent and we can infer that knowledge is also not being shared as efficiently.

The Innovate UK research collaboration data shows a similar picture but with important differences. Using this dataset, the UK research collaboration network appears more centralised around London, with the majority of LEP areas having London as their main collaboration partner. Other nodes with 6+ connections appear to act as secondary regional hubs: Enterprise M3 in the south, GCGP in the east, and Coventry and Warwickshire in the Midlands. Sheffield City region is the closest to a northern hub, with 5 connections, albeit only one of these is to another northern LEP area (Leeds). The lack of a significant sub-regional network focused around the North is indicative.

The other useful insight to come out of this analysis of Innovate UK data was the role of public sector institutions within collaboration networks. Here we found that London and Scotland have disproportionately high levels of public sector and university involvement, whereas other strong Southern LEP areas, such as GCGP, Oxfordshire and Enterprise M3 participation is dominated by private firms, with far less reliance on public sector institutions.

Stronger performing Northern (and Midland) LEPs have higher levels of university involvement than Southern LEPs, however this is not true of all Northern LEPs, with those with lower levels of overall participation also having lower relative levels of university sector participation. Cheshire & Warrington is something on an exception here. This may indicate the role of the university sector as an important leveraging factor for increasing the involvement of local firms. However, *in general*, Northern and Midland LEPs appear to be more reliant on university and public sector involvement than Southern LEPs – with the notable exception of London.

Clusters

Our rationale for doing a case study of clusters in the North (see Chapter 7) was driven primarily by an interest in exploring how the elements of the logic map played out at smaller geographies and to test the value of the map as a tool for evaluating cluster development strengths and opportunities. In this latter objective, we aimed to highlight and explore critical pathways - chains of drivers and enablers that functioned as bottlenecks or barriers in the innovation process - identified by local stakeholders. Our research focused on the digital health information systems (Leeds City Region), offshore wind energy (North East), and chemicals and process industry (North West) clusters. While these clusters were very different - in geographies, markets, stages of development, industrial structures, and strengths in the innovation process, among others - we found some interesting parallels between them.

The three clusters shared several commonalities:

- anchored by strong public entities and/or large and internationally significant firms.
- well-developed research infrastructure with universities with specialised programmes and centres, technology transfer services, and/or national labs nearby.
- robust talent pools and two of three were anchored by industry/cluster organisations.

In sum, these clusters have a lot of the necessary raw material to drive innovation. We argue that the greatest opportunities to improve performance across the innovation process centre on how to more effectively leverage local capacity and access external assets.

Arguably, all three clusters suffer from the same issues. Viewed from the outside, they appear to perform well on (aspects of) all three stages of the innovation process. However, the links between those could be more effective. For instance, all have impressive knowledge creation capacity, but they struggle to capture as much value as exists from that knowledge base. The value creation to diffusion links also appears to be weak across all three clusters. While evidence is less robust on this metric, weak knowledge circulation may be having the effect of reducing the adoption of locally generated innovations. Critically, while these clusters may perform well on the individual metrics these are the product of the activities of firms that *were able to* reach markets and *were able to* access and adopt often externally generated innovations. Capturing unrealised potential represents a significant opportunity for future cluster development.

In each case, the causes of these weak links are slightly different - the drivers and enablers involved in creating these conditions vary. However, we identified some commonalities in the critical paths particularly engaging culture and network drivers and the business base characteristics enabler.

- Weakness in cluster innovation cultures, particularly on the themes of risk tolerance and willingness to participate in knowledge sharing and open innovation processes.
- Difficulty accessing networks. Stakeholders noted that while connections existed within the cluster and sector that they were sometimes limited, or difficult for certain firms to access. This was particularly the case with respect to links with higher education and public research, strategic partnerships, and accessing potential clients and markets.

- External networks were largely ad hoc and underdeveloped. While some firms and research organisations have well-developed links, connections between entities in different clusters, even those that were relatively close proximity in the North, appear to be less developed. While we acknowledge that without more empirical research this finding is difficult to substantiate the consistency of our findings across clusters suggests that fostering cross-jurisdictional partnerships might be a significant opportunity to increase knowledge circulation and, relatedly, value creation, diffusion, and growth.
- These patterns appear to be being influenced by business base characteristics, which are similarly dominated by SMEs across clusters.

These observations were very influential in developing the recommendations addressed below but also reinforce many of the findings of the previous chapters.

8.3 Recommendations

We build on the findings described in the summary above to develop actionable recommendations for research and innovation development in the North. While the work that we've done here covers a great deal of territory, and effectively answers the questions set out at the beginning of the project, it has also raised lots of questions and suggested areas of future research. Our aim in this section is to draw together the common themes across chapters to offer some insight into the issues that are relevant across the broader Northern economy.

Reconceptualise the innovation process and its drivers

In this report, we've conceptualised innovation not as a single event, but as an interconnected process involving multiple stages. This is a dynamic and not necessarily linear process; with the right conditions, each of the links in the innovation process has the potential to stimulate activity in other phases. Recognising that knowledge creation, value creation, and diffusion (and their internal variants) function as linked elements that produce and sustain innovative outcomes enables more intelligent and effective policy design. Identifying not just which technologies a geography specialises in, but also the extent to which it is active in different stages of the innovation process, is crucial to identifying weak links and critical pathways through the innovation system. Strengthening and deepening networks both within and between LEPs is likely to be a crucial part of any policy designed to help join up the stages of the innovation process.

Similarly, our approach also views drivers and enablers as interconnected and interdependent. We see these as part of a system in which the elements influence one another, and have different impacts on different stages of the process, rather than as one-dimensional inputs. For any policy aim, we recommend thinking through not only which drivers and enablers influence outcomes, but how they combine and interact with each other to impact innovation. Our method of identifying critical pathways is one such approach. Any policy design that seeks to study and address a single driving factor in isolation is likely to misdiagnose both the problem and the solution.

Craft a unique vision for the North

It is difficult to engage in innovation policy in the UK without looking for inspiration to the South of England, as on most metrics the Southern part of the country performs better and more consistently. Indeed, our metrics identified a high-performing area incorporating London and parts of four surrounding regions, that excelled both in terms of indicators of all stages of the innovation process, but also across a wide range of drivers and enabling factors. There are specific lessons that can be learnt from the success of this region in developing an effective innovation ecosystem, particularly in the combination of factors that enable it to attract and retain both a high-skilled workforce and an entrepreneurial knowledge-focused business base.

However, the success of the South relies on a unique combination of industrial specialisations and economic geography not in evidence in the North, not least the presence of a major global city. We recommend that stakeholders within the North work to develop a vision that learns lessons from the basis of success in the South but also takes into account the specific assets, capabilities, industrial legacy, and economic geography of the North. This will involve a dual process of developing a deeper understanding of why this high-performing region in the South of England is successful (not just how), and of how this insight can be applied to the specific context of the North, with its own unique strengths and capabilities, not least its more poly-centric urban nature, its coastal assets, its enviable collection of research universities and Research Technology Organisations (RTOs), and its invaluable industrial heritage.

Build collaboration network density across the North

While strong localised cluster networks are clearly important for the innovation process, longer range networks are also critical. These provide important infusions of knowledge as firms and knowledge producers connect with other concentrations of expertise. These are also important vectors for innovation and technology diffusion that can provide new tools and inspiration to strengthen local innovation efforts. Knowledge that enters a LEP area through an external network contact can then diffuse through local networks. Organisations and individuals that interact both locally and externally have an important role.

One specific strength seen in the south of the country is the deep and dense network of collaboration between LEP areas. This shows up in both patent co-invention statistics and Innovate UK funding data. There is clearly an element of bi-causality with the overall level of innovation activity in the south, and the density of the collaboration network. However, we specifically recommend that if the North is to emulate the success of this area, it must find a way to increase the range and depth of collaboration at a pan-Northern level. We recommend that stakeholders in the North connect with other nodes in the regional and national innovation ecosystem to build and strengthen connections between firms and organisations across jurisdictional boundaries and to build a denser collaboration network both across the North and with neighbouring areas. An existing level of collaboration between organisations in the North and those in the Midlands should not be side-lined here; opportunities for complementarities, synergies and useful knowledge exchange do not only follow regional boundaries.

Identify specific opportunities in knowledge space

In chapter 4, we identified the necessity for the North as a whole to identify its role within the UK knowledge space, and for each LEP area to identify its own relatively more specialised role within this vision. The data presented in Chapter 5 provides compelling evidence of the evolving technological specialisms in the North and the detailed analysis of core technologies is a rich resource to help focus policy attention. Translating technology classes into opportunities involves a) taking stock of what industry sectors produce and exploit technological knowledge, and b) identifying where to support the development establishment of industry sectors that are currently underrepresented based on the technological profile of a region or nation.

At the scale of the North, our data indicates a number of technologies and sectors that present the opportunity for further growth in innovative output. We suggest that it is in these areas where policy intervention could be geared towards sectoral support. Developing strategies to increase the share of such sectors in the regional and national economy would be beneficial for local business creation and growth, as they would find an innovative environment that would allow them to gain a competitive advantage over firms that are based in localities where the specialized knowledge that is essential for these particular sectors is not available. Furthermore, policymakers should explore opportunities to deepen networks in order to more effectively embed them in localised, regional, and national innovation ecosystems.

8.4 Areas for Further Research

This project produced some useful insights but also suggests several more strands of research that would expand on our initial findings. While we recognise that stakeholders at various scales have roles to play in shaping the Northern innovation ecosystem, here we focus specifically on the steps that LEPs can take to better understand their role and areas of potential intervention. These have been conceptualised as broad questions to structure what we hope will be a next phase in the process of innovation ecosystem development.

- Are there commonalities in the technological specialisms and development trajectories of the LEPs that suggest potential for collaboration, cross-fertilisation, and policy co-development? Note that our research indicates that Northern LEPs might share similarities with LEPs outside of the North, which might indicate a broader potential for network development outside of the traditional geographies of the region.
- The knowledge space and recombinant knowledge potential analysis produced a wealth of data on specialisation and innovative potential for each LEP. What pathways do these particular specialisms, technological trajectories, and patterns of collaboration suggest for ecosystem development? The answers will differ for each LEP and will likely require deeper analysis of the rich results to enable each region to understand its functional strengths and its role in contributing to related variety in the North.
- Building on the previous questions and our conclusions about hierarchies of specialisation (Chapter 4) and technological relatedness (Chapter 5): What can be done to help areas within the North continue

to develop and build on their own specialisations, and then develop the right connections and networks to ensure that the right knowledge is disseminated between the organisations who can make best use of it?

- Are intra-regional networks between places in the North actually as weak as they appear in this study? If so, why, and are there opportunities to develop them? If not, how are they functioning to support the growth of localised economic activities?
- We can ask similar questions about the status of networks between Northern LEPs and other places. Which connections are most developed and why? Are there any gaps? Are there opportunities to rethink the geographies of these connections and position Northern actors more effectively within national ecosystems?
- How can we more effectively capture innovation? Patent data and collaborative research partnerships offer a window into specific types of innovation, but process innovation and other intangible outputs are difficult to systematically measure. Does innovation performance across the region differ in process versus other types of innovation? What implications does that have for productivity policy?
- Our recommendations focus on developing networks, both internally to LEPs and externally – towards national innovation ecosystems and engaging in policy co-design with partners at different scales as appropriate. However, these are not costless or simple to achieve. As partners come together to consider collaborative strategies it might be useful to explore areas in which the capacity to partner effectively, and execute expected roles, may itself benefit from intervention and support.
- The logic model proved to be a useful tool for understanding both local and more regional drivers and enablers of the innovation process and for evaluating performance. This tool can be deployed at the LEP scale to explore the entire ecosystem or can be focused, as we have done here, on understanding particular geographically-concentrated industries and the factors that drive and enable their innovation processes.