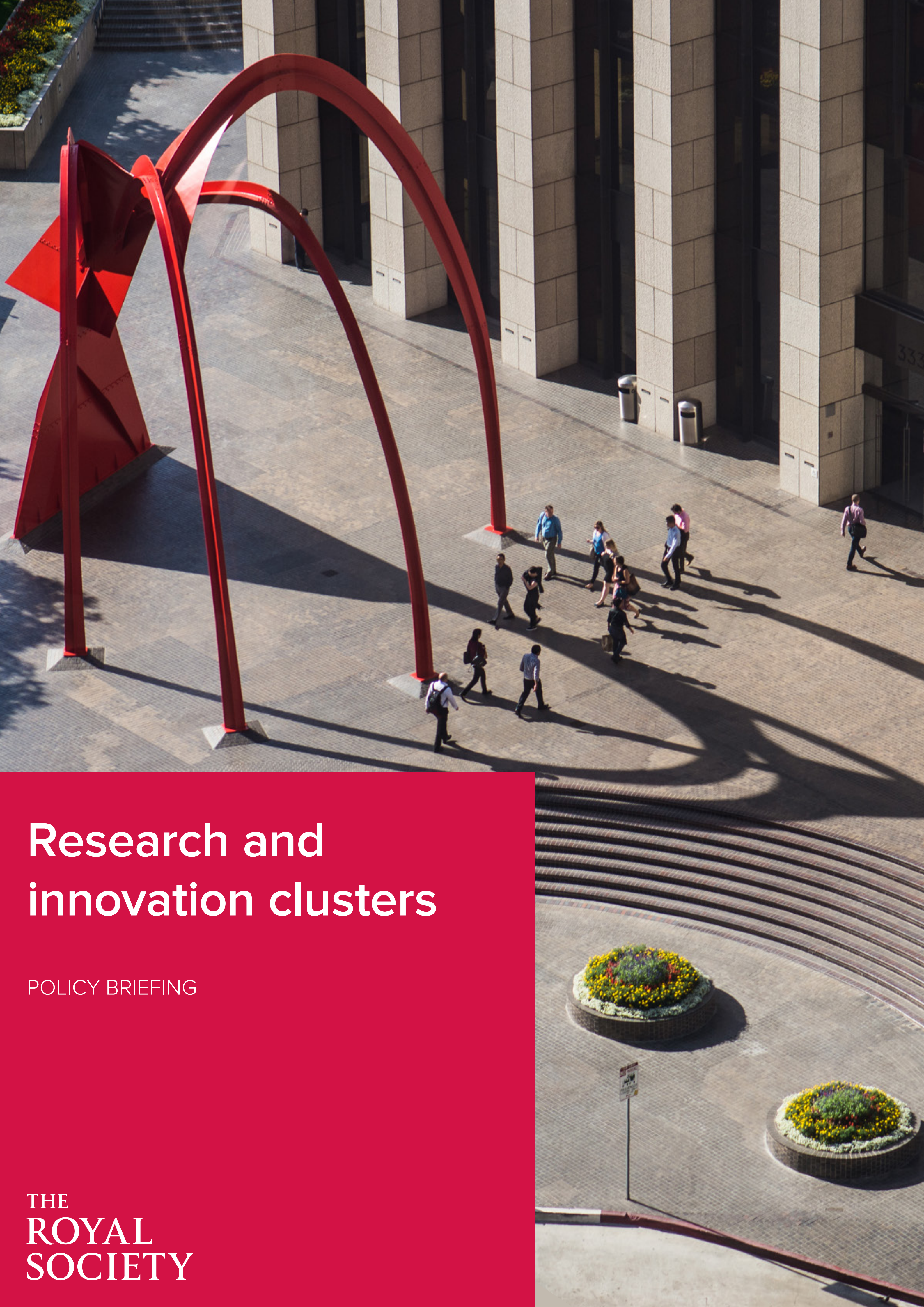

Research and innovation clusters

POLICY BRIEFING

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Policy briefing

Politics and science frequently move on vastly different timescales. A policymaker seeking evidence on a new policy will often need the answer in weeks or months, while it takes years to design and undertake the research to rigorously address a new policy question. The value of an extended investigation into a topic cannot be understated, but when this is not possible good evidence is better than none.

The Royal Society's series of policy briefings is a new mechanism aiming to bridge that divide. Drawing on the expertise of Fellows of the Royal Society and the wider scientific community, these policy briefings provide rapid and authoritative syntheses of current evidence. These briefings lay out the current state of knowledge and the questions that remain to be answered around a policy question often defined alongside a partner.

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Contents

Executive summary

There is significant divergence in economic, health and social outcomes across the UK. Locally informed place-based investment in research and development (R&D) has a role to play in improving productivity across the UK alongside complementary investments in infrastructure, skills and amenities.

Clusters are "geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages"[1]. The most famous example is Silicon Valley. The creation of new clusters in the UK appears desirable. However, successful clusters appear to be emergent and so 'creating a cluster' appears to be a misguided policy objective.

Instead, it may be useful for policymakers to consider the general factors that exist where successful clusters have emerged and focus effort toward ensuring that these are in place. A 2017 Brookings Institution report identifies the following success factors: a core competency (i.e. an area of absolute or comparative research strength); access to private and public funding; strong leadership; highly qualified researchers; business capabilities; sophisticated demand; infrastructure provision; supportive regulatory environment; a skilled workforce (commercial and technical expertise to support the research base); amenities and patience on the part of policymakers[2].

The case studies in this report describe a range of experiences, some are well-established while others are still at a relatively early stage and so a decisive assessment as to their success is premature. Taken together, the experiences of these clusters suggest that the Brookings Institution's success factors provide a valuable framework beyond the US experience[3].

This report includes eight case studies of clusters: the Belfast technology cluster, the Cambridge life sciences cluster, the Hsinchu technology cluster, the Israel technology cluster, the Pittsburgh life sciences cluster, the San Diego communications cluster, the Sheffield advanced manufacturing cluster, and the Uppsala life sciences cluster. The selection of case studies is intended to give a range in terms of geographies and maturity. The underpinning research strength for all the selected clusters relate to the Royal Society's own subject focus, and so this report does not include any examples with an arts, humanities and social sciences focus. The content of this report should be understood within these constraints.

The Belfast technology cluster has emerged over the past twenty years with considerable support from European, UK and regional government and local universities. While the knowledge economy in Northern Ireland remains small, the emerging cluster has contributed to its growth. It benefits from a core research competency, a highly skilled research base and sustained public support.

1. Delgado, Mercedes *et al*. 2014 Defining clusters of related industries, https://www.nber.org/papers/w20375.pdf (accessed on 24 May 2020).
2. Bailey, Martin Neil *et al*. 2017 Clusters and Innovation Districts: Lessons from the United States Experience, https://www.brookings.edu/wp-content/uploads/2017/12/es_20171208_baileyclustersandinnovation.pdf (accessed on 24 May 2020)
3. Swinney, Paul *et al*. 2020 Identifying potential growth centres across Great Britain, https://s3-eu-west-1.amazonaws.com/media.fc.catapult/wp-content/uploads/2020/03/11164408/Identifying-growth-centres-across-the-UK_Final.pdf (accessed on 24 May 2020).

The Cambridge life sciences cluster in one of the most successful in the world. Of the three UK case studies in this report, it is the oldest and most established. Despite the age of the University of Cambridge, it is important to note that the emergence of the life sciences cluster has taken place relatively recently. All the success factors noted by Brookings are evident.

In the last fifty years, a hugely successful semiconductor technology cluster has emerged in Hsinchu in northern Taiwan. Antithetically, its success is in large part due to continued strategic central, albeit proximate, public investment. Though this investment was in a specific technology rather than a place. At the core of this cluster is the Industrial Technology Research Institute (ITRI). The importance of 'patience' as a success factor is evident in this case study.

The only country to appear among the case studies, Israel's technology cluster is concentrated within an area half the size of Silicon Valley. Globally competitive, the cluster has emerged since the 1960s, benefitting from strong networks between the public and private sector, in part a consequence of military service, significant investment in R&D and a highly skilled workforce.

The emergence of a strong life sciences cluster alongside complementary activity in advanced manufacturing and technology have helped to transform Pittsburgh's economy since the breakdown of traditional industry in the late 1970s. This change was enabled by deliberate action from local leaders able to take advantage of civic and philanthropic investments made twenty years earlier.

Over the twentieth century, San Diego grew from relative obscurity to a thriving technology-led economy. This growth began with the presence of a naval base and military contractors and led to the creation of a research-intensive university that has grown in tandem with the local communications industry.

The development of a nascent cluster in advanced manufacturing in former industrial centre Sheffield offers hope to those seeking to stimulate R&D-led growth in regions that have suffered from de-industrialisation. The University of Sheffield, itself partially a product of the city's industrial heritage, has been central to this development as has local industry together with local leadership and the significant allocation of funding for redevelopment initiatives.

The Uppsala life sciences cluster in Sweden has much in common with the development of other notable clusters: a strong university research base, a proliferation of innovative firms, and key individuals who mobilise and attract funding and garner wider interest in their work. It builds on Sweden's solid foundation for life sciences research. Local initiatives have worked to promote and popularise its status as a cluster.

Finally, the purpose of this report is not to recommend the creation of clusters as a policy objective but illustrate the range of factors that may need to be in place for research and innovation-led regional development to take place. The success factors identified by Brookings and noted above appear in whole or in part in all case studies. Policymakers should encourage R&D-led regional growth by considering what could be done at a national and local level to ensure that these success factors exist in as wide a distribution of places as is practicable. In many cases, this will be ensuring adequate sustained levels of funding for research, amenities (e.g. good schools, cultural attractions, leisure facilities), education and training and infrastructure. Where new effort is being expended to create or strengthen these factors, meaningful local engagement will be critical to success. In the UK context, the central importance of comparative research strength, a skilled workforce, as well as the generally positive impact of university presence on economic growth[4], taken together with an already wide geographic spread of higher education institutions provides some guidance as to an approach.

Structure

This report is composed of two sections. The first section includes a brief discussion of the current context and the cluster model. The second section of this report includes eight case studies:

- Belfast technology cluster;
- Cambridge life sciences cluster;
- Hsinchu technology cluster;
- Israel technology cluster;
- Pittsburgh life sciences cluster;
- San Diego communications cluster,
- Sheffield advanced manufacturing cluster; and
- Uppsala life sciences cluster.

4. Valero, Anna *et al*. 2019 The Economic Impact of Universities: Evidence from Across the Globe, https://www.sciencedirect.com/science/article/pii/S0272775718300414 (accessed on 24 May 2020).

Chapter one

Context

Introduction

Currently over half of R&D investment is concentrated in three regions of the UK: the East of England, London and the South East. This concentration of investment reflects a broader disparity in regional economic performance, prompting a characterisation of the UK as "two countries"[5]. This disparity hinders national growth and can engender social resentment and disaffection[6].

The full economic impact of the coronavirus crisis is not yet clear but likely to be severe. It appears that it will cut across industries and individuals in ways that are complex and do not neatly align with geography. Nonetheless, the extent to which its economic repercussions are felt most severely by low-income families suggests that it is more likely to entrench existing regional inequality[7].

Improving economic performance comes from increased employment and higher productivity[8]. Productivity "measures how efficiently production inputs, such as labour and capital, are being used in an economy to produce a given output"[9]. While pre-COVID-19 employment levels in the UK were high, overall productivity growth in the UK has been flat since the 2008 financial crisis, though this varies massively within and between regions[10].

Investment in R&D is one means to achieve productivity growth: "The creation and application of new ideas is critical for long-run productivity growth. There is clear and robust evidence of a link between R&D spending and national productivity"[11].

The Government's commitment to increase funding in R&D and ensure that the benefits of this investment are more widely felt is welcome[12]. Care is needed to ensure that this increase is delivered judiciously. Most R&D funding is distributed on an assessment of research excellence. Existing research strength should be protected. However, there is a role for complementary initiatives that support the development of research strength at a local level. 'Place' should be considered in the allocation of any real terms increase in funding.

5. Jones, Richard. 2019 A Resurgence of the Regions: rebuilding innovation capacity across the whole UK, http://www.softmachines.org/wordpress/wp-content/uploads/2019/05/ResurgenceRegionsRALJv22_5_19.pdf (accessed on 24 May 2020).
6. Rodrigues-Pose, Andres. 2018 The revenge of the places that don't matter, https://voxeu.org/article/revenge-places-dont-matter (accessed on 24 May 2020).
7. Banks, James *et al*. 2020 Recessions and health: the long-term health consequences of responses to the coronavirus, https://www.ifs.org.uk/publications/14799 (accessed on 24 May 2020).
8. HM Treasury. 2015 Fixing the foundations: Creating a more prosperous nation, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/443898/Productivity_Plan_web.pdf (accessed on 24 May 2020).
9. Krugman, Paul. 1994 The Age of Diminishing Expectations
10. McCann, Philip. 2019 A Place-Based Shift?, https://www.ifm.eng.cam.ac.uk/uploads/Research/CSTI/UKRI_Place/McCann_-_UK_Research_and_Innovation_-_A_Place-Based_Shift_vFinal.pdf (accessed on 24 May 2020).
11. HM Treasury. 2015 Fixing the foundations: Creating a more prosperous nation. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/443897/Productivity_Plan_print.pdf (accessed on 03 July 2020).
12. HM Treasury. 2020 Budget 2020, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/871799/Budget_2020_Web_Accessible_Complete.pdf (accessed on 24 May 2020).

Place-based research funding

European Union Structural and Investment Funds

Historically, few R&D funding schemes in the UK have been focused on place. As some of the following case studies illustrate, European Union Structural and Investment Funds have played an important role in the development of regional research and innovation infrastructure. Between 2014 – 2020, the UK was allocated approximately £15 billion of structural funding from the EU. In absolute terms, during this period, England received the bulk of this funding, but in terms of funding per person, Wales received the highest amount (on average £140 per person per year), followed by Northern Ireland, Scotland and then England. Within this, allocations differed between regions on the basis of relative economic prosperity. This funding comes through four schemes, the European Agricultural Fund for Regional Development (EAFRD), the European Maritime and Fisheries Fund (EMFF), the European Regional Development Fund (ERDF), and the European Social Fund (ESF[13]).

Funding to support research and innovation comes principally through the ERDF. Between 2014 – 2019, the UK received £426.5 million of research and innovation funding through this route[14].

Shared Prosperity Fund

Having left the European Union, the UK will no longer be eligible to receive European Structural Funds. The Government has announced the Shared Prosperity Fund (SPF) as a mechanism to replace this funding. The form of this Fund has not yet been defined. Its stated objective is to "reduce inequalities between communities across our four nations"[15]. The past importance of European Structural Funds suggests that the SPF should be central to building new regional research and innovation capability.

Strength in Places Fund

The Strength in Places Fund (SIPF) is a current mechanism for place-based funding that has been developed by UK Research and Innovation (UKRI). It was announced in the 2017 Industrial Strategy White Paper. Money for the fund is drawn via the National Productivity Investment Fund rather than the Research and Innovation budget[16]. The SIPF seeks to build on "existing research excellence and high-quality innovation capability". Specifically, it aims to "Support innovation-led relative regional growth by identifying and supporting areas of R&D strength that are:

- Driving clusters of business across a range of sizes that have potential to innovate, or to adopt new technologies;
- In order that these clusters will become nationally and internally competitive"[17].

At the time of writing, the SIPF has invited two waves of applications. It is relatively modest in size, with a total funding allocation of £2 million in 2018/19, £32 million in 2019/20 and £82 million in 2021/22.

13. Brien, Philip. 2019 The UK Shared Prosperity Fund, https://commonslibrary.parliament.uk/research-briefings/cbp-8527/ (accessed on 24 May 2020).
14. *Ibid.*
15. The Conservative and Unionist Party. 2017 Forward, together: Our plan for a stronger Britain and a prosperous future, https://s3.eu-west-2.amazonaws.com/conservative-party-manifestos/Forward+Together+-+Our+Plan+for+a+Stronger+Britain+and+a+More+Prosperous....pdf (accessed 24 May 2020).
16. National Academies. 2019 UKRI Explainer, https://royalsociety.org/-/media/policy/Publications/2019/03-10-19-ukri-explainer.pdf (accessed on 24 May 2020).
17. UK Research & Innovation. 2019 UKRI Strength in Places (SIPF) Wave 2 Programme Overview, https://www.ukri.org/files/funding/ukri-strength-in-places-wave-2-programme-overview/ (accessed on 24 May 2020).

The cluster model

The description and identification of clusters has been an area of live academic debate for over twenty years. The standard definition by Michael Porter follows:

"Clusters are geographic concentrations of interconnected companies and institutions in a particular field. Clusters encompass an array of linked industries and other entities important to competition. They include, for example, suppliers of specialized inputs such as components, machinery, and services, and providers of specialized infrastructure. Clusters also often extend downstream to channels and customers and laterally to manufacturers of complementary products and to companies in industries related by skills, technologies, or common inputs. Finally, many clusters include governmental and other institutions—such as universities, standards-setting agencies, think tanks, vocational training providers, and trade associations—that provide specialized training, education, information, research, and technical support[18]."

In brief, clusters tend to be understood by policymakers as, "geographic concentrations of industries related by knowledge, skills, inputs, demand, and/or other linkages"[19]. Proponents argue that clusters have a positive effect on competition by, "increasing the productivity of companies based in the area; driving the direction and pace of innovation, which underpins future productivity growth; and by stimulating the formation of new business, which expands and strengthens the cluster itself"[20].

While the concept of clusters is relatively recent, geographic concentrations of related industries are not. Historic examples in the UK, include the cotton industry in Lancashire during the nineteenth and first half of the twentieth century, and ceramic production in Staffordshire from the seventeenth century to the early twentieth century. Early twentieth-century economist Alfred Marshall described this as 'compound localisation' and the regions as 'industrial districts[21]' – echoed in the recent term 'innovation districts[22]'. The key advantages for firms of being based in a relevant industrial district included a local pool of skilled labour, local supplier linkages and local knowledge spillovers[23].

18. Porter, Michael E. 1998 Clusters and the New Economics of Competition, https://hbr.org/1998/11/clusters-and-the-neweconomics-of-competition (accessed on 24 May 2020).
19. Delgado, Mercedes *et al*. 2014 Defining clusters of related industries, https://www.nber.org/papers/w20375.pdf (accessed on 24 May 2020).
20. Porter, Michael E. 1998 Clusters and the New Economics of Competition, https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition (accessed on 24 May 2020).
21. Belussi, Fiorenza *et al*. 2009 At the origin of the industrial district: Alfred Marshall and the Cambridge school, https://academic.oup.com/cje/article/33/2/335/1732562 (accessed on 24 May 2020).
22. Bailey, Martin Neil *et al*. 2017 Clusters and Innovation Districts: Lessons from the United States Experience, https://www.brookings.edu/wp-content/uploads/2017/12/es_20171208_bailyclustersandinnovation.pdf (accessed on 24 May 2020).
23. Belussi, Fiorenza *et al*. 2009 At the origin of the industrial district: Alfred Marshall and the Cambridge school, https://academic.oup.com/cje/article/33/2/335/1732562 (accessed on 24 May 2020).

Clusters exist in a range of industries across the globe. The archetype is Silicon Valley in the US[24]. The emergence of Silicon Valley is due to both contingent and general factors. The latter of which include the presence of a highly skilled workforce (in this case associated with local research-intensive universities), public and private sector investment and supportive government policy. The scale of Silicon Valley's success may be singular – in 2017 its economic output was higher than Finland[25] – but the general factors that contributed to its success are visible elsewhere. A review of clusters across the US by the Brookings Institution, suggests the following success factors: a core competency; access to private and public funding; strong local leadership; a skilled workforce (both in terms of the core competency and general business practice); demand; infrastructure provision; and a supportive culture[26].

Conversely, cluster initiatives tend to fail when they do not take proper account of the local conditions and strengths of the region in which they are being established. This can occur when the initiative is designed centrally and imposed upon a region without the proper consideration of local factors that could have been provided through the participation of the target community.

Successful clusters like Silicon Valley can yield tremendous economic gain for the regions and countries in which they're based. The case studies included in this report provide some examples of the positive effects that they have on their regional and national economy. However, policymakers should avoid seeking to consciously create new clusters. As economic geographer Max Nathan notes, "the cluster is an emergent property of these interactions [entrepreneurs, firms and workers] it is very difficult to make policy that targets cluster outcomes and manipulate the cluster itself"[27]. Consequently, while the 'creation of a cluster in X' is a misguided policy ambition, it does seem useful for policymakers to try and create the conditions that allow clusters to emerge – including through the provision of public investment in R&D.

24. Engel, Jerome *et al*. 2015 Global Clusters of Innovation: Lessons from Silicon Valley, https://journals.sagepub.com/doi/pdf/10.1525/cmr.2015.57.2.36 (accessed on 24 May 2020).
25. Pulkikinen, Levi. 2019 If Silicon Valley were a country, it would be among the richest on Earth, https://www.theguardian.com/technology/2019/apr/30/silicon-valley-wealth-second-richest-country-world-earth (accessed on 24 May 2020).
26. Bailey, Martin Neil *et al*. 2017 Clusters and Innovation Districts: Lessons from the United States Experience, https://www.brookings.edu/wp-content/uploads/2017/12/es_20171208_bailyclustersandinnovation.pdf (accessed on 24 May 2020).
27. Nathan, Max *et al*. 2013 Agglomeration, clusters and industrial policy, http://personal.lse.ac.uk/nathanm/downloads/oxrep2013.pdf (accessed on 24 May 2020).

Chapter two

Case studies

Belfast technology cluster

Introduction

In the first half of the twentieth century, the economy in Belfast was dominated by manufacturing with most of the workforce employed in manufacturing roles. However, from the 1950s onwards these industries began to collapse[28]. Concurrent with the period of sectarian violence, Northern Ireland experienced a period of economic decline from the late 1960s to the 1990s. By 1991, only around 15% of the workforce was employed in manufacturing employment. From the early 1970s onwards unemployment in Northern Ireland was consistently between around two and six percentage points higher than the UK average, peaking in 1986 at 18%[29].

While challenges remain, Belfast has seen growth since the late 1990s. The knowledge economy is a small part of the regional economy, but the second-fastest growing in the UK for the fifth consecutive year in 2018[30]. Catalyst, formerly known as the Northern Ireland Science Park, has played an important part in this growth.

Catalyst has its main site in Belfast's Titanic Quarter. The Quarter is one of the world's largest urban-waterfront regeneration projects, occupying over 185 acres. It is the site of a former ship-building yard - the Titanic was built on the site. The project originated as part of a package of economic measures that followed the signing of the Good Friday Agreement in 1998. Redevelopment of the site began in 2002. In 2018, 2,700 people came to work at 174 companies across Catalyst's four sites.

Development

Early discussion on the creation of a 'Research and Enterprise Park' in Belfast began in 1994 at a Queen's University Belfast management retreat. The idea was generated by staff, including Professor John McCanny, following visits to places such as Hsinchu Science Park in Taiwan and Silicon Valley in the US.

Initial scoping work for the Northern Ireland Science Park (NISP) began in 1997. The work was commissioned by the Department for Enterprise, Trade and Investment (DETI). Following the signing of the Good Friday Agreement in April 1998, a package of economic initiatives was announced for Northern Ireland including £10 million pledged for the creation of a new Science Park (DETI 2010). Northern Ireland Science Park Limited (NISP), a not-for-profit organisation limited by guarantee was created in March 1999.

28. Lane, Laura *et al*. 2016 Belfast City Story, http://eprints.lse.ac.uk/67850/1/casereport102.pdf (accessed on 16 January 2020).
29. Gudgin, Graham. 1999 The Northern Ireland Labour Market, https://www.thebritishacademy.ac.uk/sites/default/files/98p251.pdf (accessed on 16 January 2020).
30. Catalyst Inc. 2018 The 2018 Northern Ireland Knowledge Economy Report, https://wearecatalyst.org/wp-content/uploads/2019/08/Knowledge-Economy-Report-2018.pdf (accessed on 16 January 2020).

At its outset, the objectives for the park were:

- "To assist with the long-term development of the Northern Ireland economy by acting as a catalyst for change and enhancing the opportunities for wealth creation;
- To promote the commercial development of university research by strengthening the links between business and the two universities [Queens University Belfast and Ulster University];
- To encourage the establishment of technology-based business (both indigenous and FDI) in Northern Ireland; and
- To foster research, design and development by business in Northern Ireland through the commercial application of technology and business education resources generated in the universities"[31].

In August 2000, Norman Apsley joined NISP as Chief Executive from a position as Director of Electronics and Site Director of the (now defunct) Defence Evaluation and Research Agency (DERA). In 2000, the site agreement with NISP and the Titanic Quarter was signed. In 2003, the Innovation Centre was completed.

Queen's University Belfast and Ulster University have been involved in the Northern Ireland Science Park since its inception. The Institute for Electronics, Communications and Information Technology (ECIT) was established with £40 million of funding (including support from InvestNI, the Department of Employment and Learning and the EU Peace and Reconciliation Programme) in the Titanic Quarter in 2005, and now acts as an anchor institution.

In 2006, Broadsoft opened its European Headquarters at NISP.

In 2008, NISP Connect was established. A collaboration between NISP, the Agri-Food and Biosciences Institute (AFBI), Queen's University Belfast and Ulster University with funding from the European Regional Development Fund, it was established to support early-stage and established companies to grow.

By 2009, the park was home to 55 companies employing 740 people. In the same year, the Centre for Secure Information Technologies (CSIT) was established within ECIT. CSIT was established with funding support from the Engineering and Physical Science Research Council (EPSRC), the Technology Strategy Board (now Innovate UK / UKRI) and InvestNI.

In 2011, the Belfast Metropolitan College opened in the Titanic Quarter.

By 2014, NISP was home to 120 businesses employing 2,000 people. A second campus, the Innovation Centre, was opened.

In 2016, NISP changed its name to Catalyst Inc (latterly Catalyst) and announced a major expansion plan of a million square foot of new office space over the next ten years. Later in the year, PathXL, a digital pathology company based at NISP that had been established in 2004 by two Queen's University Belfast faculty members, was acquired by Philips[32].

In 2018, Norman Apsley stood down as CEO and was replaced by entrepreneur Steve Orr who had returned from San Diego in 2008 to set up NISP Connect. The Catalyst Belfast Fintech Hub was opened with Danske Bank in Belfast City Centre.

31. Department of Enterprise, Trade & Investment. January 2010 Evaluation of the Northern Ireland Science Park: Final report, http://www.jobsandgrowthni.gov.uk/downloads/DETI_IPU_1.2.1_30679_Northern_Ireland_science_Park_%28NISP%29_Evaluation_-_final_-_Jan_10.PDF

32. Philips. 2016 Philips expands its Digital Pathology Solutions portfolio with the acquisition of PathXL, https://www.philips.co.uk/healthcare/sites/pathology/release-press/20160621-philips-expands-its-digital-pathology-solutions-portfolio-with-the-acquisition-of-pathxl (accessed on 16 January 2020).

By 2019, Catalyst was home to 174 businesses employing 2,700 people. Expanding further, the Innovation Centre was launched in the nearby town Ballymena in partnership with Mid and East Antrim Borough Council.

In March 2019, the UK Government approved the Belfast City Deal – a £350 million programme of investment over the next 15 years[33]. It includes a range of proposals for investment in innovation and digital capabilities that have been developed in collaboration by Queen's University Belfast and Ulster University.

Outcomes

The last twenty years have seen Northern Ireland consistently suffer from low productivity growth, with individual Gross Value Added (GVA) per capita, ranking 10th of 12 UK regions in 2018. In part, this is a reflection of its sectoral employment composition. Relative to the UK average, Northern Ireland has a high concentration of "employment in lower value adding sectors such as agriculture, retail and health and social work"[34].

In 2018, the knowledge economy employed 40,250 people (4.7% of total employment). In 2016, it accounted for 5.9% of total GVA (£2.2 billion). This was an increase of 6.3% from the previous year, compared to a figure of 1.7% for the overall economy. It is the 4th fastest growing knowledge economy in the UK, but it remains small both in terms of its contribution to the overall economy and relative to other regions in the UK. The concentration of knowledge economy firms in East Belfast around Catalyst's site in the Titanic quarter, account for around 13.4% of the knowledge economy in Northern Ireland[35].

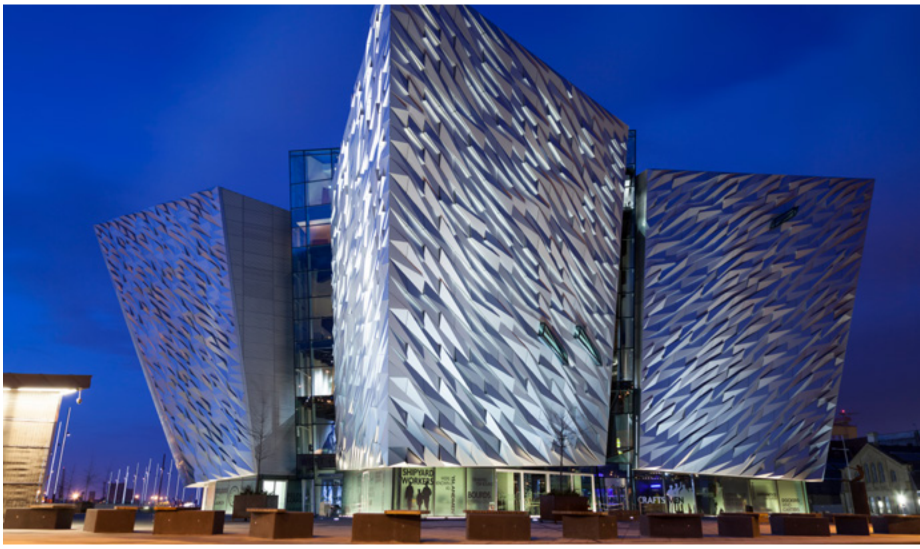

Image:
Titanic Visitor Centre Building In Belfast Northern Ireland. © Feverstockphoto.

Within Catalyst, the Centre for Secure Information Technologies (CSIT) has formed the centre of a local cybersecurity ecosystem that includes over forty companies. These companies "[employ] approximately 1600 cybersecurity professionals delivering £60 million per annum in salaries to the local economy. The cybersecurity industry supports approximately 750 additional jobs in the wider economy"[36].

Looking forward

The Belfast technology cluster centred around Catalyst's location in the Titanic Quarter is an important part of Northern Ireland's small but growing knowledge economy. Broader economic challenges remain in the region and the impact of leaving the European Union presents an immediate test, with specific concerns around the ability to attract and retain the skilled workforce necessary to deliver intended growth. The Belfast City Deal includes significant provision for investment in innovation and infrastructure and it is hoped it will support the ambitions for growth.

33. Belfast City Council. 2019 Belfast Region City Deal – it's a big deal, http://www.belfastcity.gov.uk/buildingcontrol-environment/regeneration/city-growth-deal.aspx (accessed on 16 January 2020).
34. Johnston, Richard *et al*. 2019 Understanding Productivity in Northern Ireland, https://www.ulster.ac.uk/__data/assets/pdf_file/0005/414662/Understanding-Productivity-in-NI-May-2019.pdf (accessed on 16 January 2020).
35. NISP Connect. 2015 The Knowledge Economy in Northern Ireland, https://www.ulster.ac.uk/__data/assets/pdf_file/0008/181439/NI-KEI-Report-2015.pdf (accessed on 16 January 2020).
36. Queen's University Belfast. 2019 CSIT '10 Years of Impact', https://www.qub.ac.uk/home/Filestore/Filetoupload,894422,en.pdf (accessed on 16 January 2020).

Cambridge life sciences cluster

Introduction

The 'Cambridge phenomenon' describes the emergence of a cluster of 'high-tech' industries in and around Cambridge. The term was coined in 1980 and its continued use reflects the sustained economic performance of the city-region[37].

People have sought to identify antecedents to the success of the cluster in the establishment of the Cambridge University Press in 1534, the creation of Cambridge Scientific Instruments by Sir Horace Darwin in 1896 and the formation of aerospace company Marshall's in 1909. Generally, the inception of the cluster is linked to the establishment of Cambridge Consultants by Tim Elioart and David Southward in 1960.

Cambridge has emerged as a highly competitive cluster in which companies can attract venture capital investment from across the world. This case study focuses on the life sciences cluster. It exists within a broader cluster of research-intensive industries, with particular strengths in software and computing - illustrated by the success of the companies ARM, Autonomy and their predecessors. Consequently, the life sciences cluster has been described as a 'sub-cluster[38]' which exists within a broader context of complementary innovation.

Development

The establishment of Cambridge Consultants in 1960 with its ambition to 'put the brains of Cambridge University at the disposal of British Industry' took place in a town that was "still viewed by many as a small country town in the centre of a very large natural green belt"[39]. While there were individuals with ambition, there was not a physical infrastructure to support effective translation and innovation. This came with the establishment of Cambridge Science Park in 1970.

The impetus for the Science Park's establishment came in 1964. At a national level, the Government was encouraging "UK universities to expand their contact with industry with the objective of technology transfer to increase the payback from investment in basic research and an expansion in higher education in the form of new technologies"[40]. In response, the University of Cambridge set up a committee under the Chairmanship of Sir Nevill Mott, Cavendish Professor of Experimental Physics. The Mott Report was published in 1969. It recommended increased activity in science-based industry. Following its publication, Trinity College took forward the ideas of the report and established the Cambridge Science Park on a plot of land in north-west Cambridge. This foundational infrastructure has since been complemented by the St John's Innovation Centre (1987), the Wellcome Trust Genome Campus (1994) – home to the Sanger Institute, the Babraham Research Campus (1998), and the Cambridge Biomedical Campus (2013) – now home to the Medical Research Council (MRC) Laboratory of Molecular Biology (LMB).

In their book, 'The Cambridge Phenomenon[41]', Charles Cotton and Kate Kirk trace the development of genomics and monoclonal antibodies technologies and their contribution to the emergence of the life sciences cluster. Both technologies have their roots in research

37. Levi, Peta. 1980 Flourishing in the Cambridge parkland, https://alanbarrell.com/wp-content/uploads/2018/09/AB-K-Kirk-Cam-Phen-10-Sept-20182.pdf (accessed on 16 January 2020).
38. Tyler, Pete *et al*. 2015 The Cambridge Bioscience Impact Assessment Study, https://www.phpc.cam.ac.uk/pcu/files/2015/09/CambridgeBioscienceImpact.pdf (accessed on 16 January 2020).
39. Cambridge Consultants. 2020 About Us, https://www.cambridgeconsultants.com/about-us (accessed on 16 January 2020).
40. Cambridge Science Park. 2020 48 years of history & 700 years of heritage, https://www.cambridgesciencepark.co.uk/about-park/past/ (accessed on 16 January 2020).
41. The Cambridge Phenomenon. 2020 The Cambridge Phenomenon, http://www.cambridgephenomenon.com/phenomenon/ (accessed on 16 January 2020).

undertaken at the LMB and its precursor, the 'Unit for Research on the Molecular Structure of Biological Systems' – also funded by the MRC.

The academic origin of genomics technology is in the work of Crick and Watson in the 1950s that resulted in the discovery of the structure of DNA, the work of Fred Sanger in 1970s that led to the first genome sequencing at the LMB and the subsequent development of a new approach to DNA sequencing by Shankar Balasubramaniam and David Klenerman in the 1990s. Balasubramaniam and Klenerman's work to develop a new approach to DNA sequencing was supported by £282,000 in BBSRC funding in 1996[42].

With assistance from Richard Jennings, Director of the Wolfson Cambridge Industrial Liaison Office, Balasubramaniam and Klenerman secured venture capital from London firm Abingworth and established a start-up that then became Solexa. Following the expansion of its core team and the acquisition of a Swiss company called Manteia, Solexa went on to sequence its first whole genome in 2005. The first Solexa machine, the 1G Genetic Analyzer, shipped in 2006. In November of the same year, Solexa was acquired for $650 million by US company Illumina[43]. Illumina is now worth around $30 billion. Its EMEA headquarters remain in Cambridge at the Wellcome Genome Campus.

The academic origin of monoclonal antibodies technology is in the work George Kohler and Cesar Milstiein in the 1970s. In the 1980s, Gregory Winter, also at the LMB, invented the first humanised monoclonal antibody.

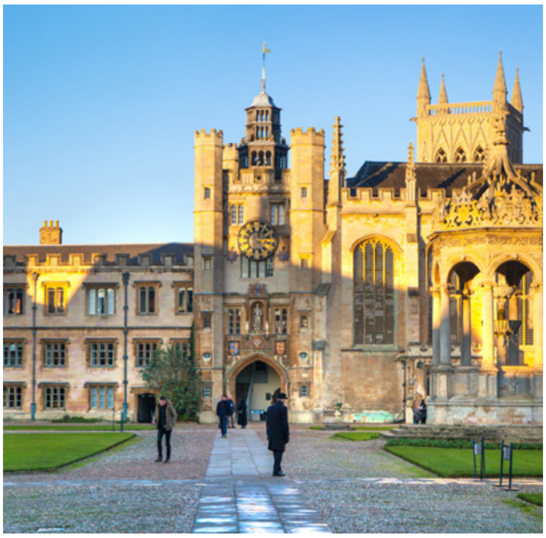

Image
Trinity College Cambridge.
© IR_Stone.

Winter went on to found Cambridge Antibody Technology (CAT) with David Chiswell and John McCafferty in 1989[44] with £750,000 from Australian company Peptechn and investment from the MRC. In the early 1990s, CAT began a collaboration with Knoll Pharmaceuticals. The result of this collaboration was the development of the adalimumab, which is used to treat rheumatoid arthritis, psoriasis and inflammatory bowel diseases. Adalimumab was approved in 2002 and launched in 2003 as Humira. CAT grew to 300 employees and in 2006 was acquired by AstraZeneca for £702 million. Gregory Winter, who was awarded the Nobel Prize in 2018, has gone on to launch two further companies: Domantis and Bicycle Therapeutics. Domantis was established in 2000 and had grown to 70 staff when it was acquired by GlaxoSmithKline for £230 million in 2006. Bicycle Therapeutics was founded in 2009. It is jointly headquartered in Cambridge at the Babraham Research Campus and Boston in the US.

42. BBSRC. 2016 DNA sequencing tackles global challenges, https://bbsrc.ukri.org/documents/1607-dna-timeline/ (accessed on 16 January 2020).
43. The Cambridge Phenomenon. 2020 The Cambridge Phenomenon, http://www.cambridgephenomenon.com/phenomenon/ (accessed on 16 January 2020).
44. Walsh, Louise. 2019 A very Cambridge story, https://www.cam.ac.uk/antibodies (accessed on 16 January 2020).

Outcomes

The life sciences sector contributes over £30 billion to the UK economy every year. A 2018 report commissioned by AstraZeneca attributed £2.9 billion of that figure to companies based in Cambridge. The cluster includes over 430 companies, collectively employing over 15,500 people.

An earlier impact assessment study from 2013, estimated the direct contribution of the Cambridge life sciences cluster to the UK economy as £907 million in gross value added and 13,800 jobs. This accounted for 7.6% of all employment in Cambridge and 11.4% of the total value-added. When including indirect and induced effects this rose to £1.54 billion in gross value added and 25,300 jobs. Employment in Cambridge in the life sciences as a proportion of total employment is 2.5 times higher than the national average (2.5%). The life sciences sector has grown at a higher rate that the regional economy since the 1980s, though at a relatively slower rate than other high-tech sectors within the local economy[45].

The economic success of the life sciences cluster is reflected in the academic performance of related subjects at the University of Cambridge. In the 2014 Research Excellence Framework exercise, the University was among the top three institutions for the percentage of 4* (quality that is world leading in terms of originality, significance and rigour) outputs in the units of assessment Clinical Medicine; Public health, Health services and Primary care; and Psychology, Psychiatry and Neuroscience. It also performing highly in Biological Sciences and Agriculture, Veterinary and Food Science.

Looking forward

AstraZeneca moved their global campus to Cambridge in 2016. They are currently building a £500 million campus in the Cambridge Biomedical Campus, scheduled for completion this year. This expansion is illustrative of a general expectation that the cluster shall continue to grow. If this growth takes place at the current rate, the cluster could contribute an additional £1 billion per annum to the economy by 2032 and create 6,000 additional jobs[46].

Risks to this expected growth, include any impact of a loss of access to EU funding programmes on the research base and increased barriers and a reduced ability to attract R&D talent. More locally, a survey of business on the Babraham Business Park ranked the costs of housing and commuting problems as the most important constraints to recruiting employees[47]. A second train station close to Cambridge Science Park, Cambridge North, was opened in 2017, but challenges remain with increasing property prices and congestion.

45. *Op. ci.* note 38.
46. Development Economics. 2018 Cambridge: driving growth in life sciences – Exploring the value of knowledge-clusters on the UK economy and life sciences sector, https://www.astrazeneca.com/content/dam/az/media-centre-docs/article_files/articles-2018/Astrazeneca-Clusters-Report-Exec-Summary%20FINAL%202.pdf (accessed on 16 January 2020).
47. *Op. ci.* note 38..

Hsinchu technology cluster

Introduction

Over the past forty years, Taiwan has emerged as a highly developed economy. In 2016, its GDP per capita was $42,304[48]. In 2017, it accounted for "6-7% of global trade in ICT products"[49]. Hsinchu, in the north of the island, around 70km from Taipei, has played a central role in this growth.

In 1973, at the point the Industrial Technology Research Institute's (ITRI) creation in Hsinchu, Taiwan had already experienced twenty years of rapid economic growth, albeit from a low base. Capital poor, but labour rich, the economy in the 1950s and early 1960s was dominated by import-substitution industry, shifting to export-oriented industry through the 1960s[50]. This shift was partially a result of the creation of Export Processing Zones (EPZs) by the Government. International and domestic firms operating in EPZs received tax incentives provided that most goods created were exported. This supported the development of local firms, particularly those operating in the textiles and electronics industries. Still, in 1973, Taiwan remained a developing economy with a GDP per capita of $6,192 (International $ (2011 prices))[51],[52].

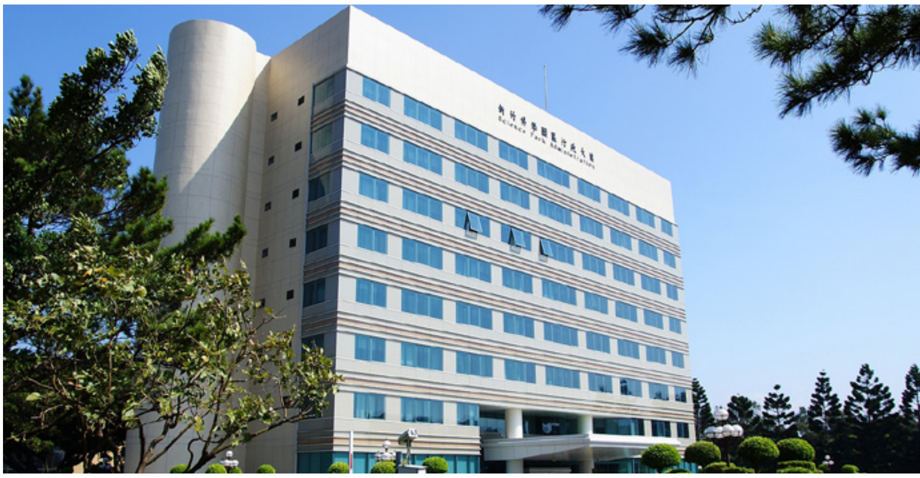

Image
Hsinchu Science Park administration building.

Development

ITRI was founded under the impetus of Sun Yun-suan, then Minister for Economic Affairs. Sun, who later became Premier, had trained as an engineer in the US. He sought to 'drive Taiwan's climb up the technology ladder[53].' Assisted by others, notably K.T. Li, a Cambridge-trained economic planner who had also been involved in the establishment of EPZs, a proposal to establish ITRI was submitted to the Taiwanese Legislative in 1972. The bill passed and the organisation was established the following year with a staff of 400 as an amalgamation of the existing public R&D organisations for general industry, mining industry and metallurgical industry[54].

48. (International $ (2011 prices)) Maddison Project Database. 2018 GDP per capita, 1950 to 2016, https://ourworldindata.org/grapher/average-real-gdp-per-capita-across-countries-and-regions?time=1950..&country=TWN (accessed on 24 May 2020).
49. UK Science & Innovation Network. 2018 UK Science & Innovation Network Snapshot - Taiwan, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/723761/SIN_Taiwan_snapshot_November_2017__Updated_Contacts_.pdf (accessed on 24 May 2020).
50. Courtenay, Philip. 1993 Taiwan's Hsinchu science-based industrial park, https://www.jstor.org/stable/pdf/40572559.pdf?ab_segments=0%252Fbasic_SYC-5152%252Fcontrol&refreqid=excelsior%3Acc682f34ca2ee5e8ac7203cc8b5f92b2 (accessed on 24 May 2020).
51. Maddison Project Database. 2018 GDP per capita, 1950 to 2016, https://ourworldindata.org/grapher/average-real-gdp-per-capita-across-countries-and-regions?time=1950..&country=TWN (accessed on 24 May 2020)
52. For comparison, GDP per capita in the UK for the same year was $17,116 ((International $ (2011 prices)). Maddison Project Database. 2018 GDP per capita, 1950 to 2016, https://ourworldindata.org/grapher/average-real-gdp-per-capita-across-countries-and-regions?time=1950..&country=TWN (accessed on 24 May 2020).
53. Hu, Mei-Chih. 2011 Evolution of knowledge creation and diffusion: the revisit of Taiwan's Hsinchu Science Park, https://akjournals.com/view/journals/11192/88/3/article-p949.xml (accessed on 24 May 2020).
54. Wade, Robert. 2003 Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization, https://press.princeton.edu/books/paperback/9780691117294/governing-the-market (accessed on 24 May 2020).

Following a conversation in 1974 between Sun and Dr Pan Wen-Yuan, an engineer employed at RCA's David Sarnoff Laboratories in New Jersey[55], a concerted effort to build a semiconductor industry in Taiwan began. In 1974, the Electronics Industry Research & Development Centre (latterly Electronics Research and Service Organisation (ESRO)) was established at ITRI, to create a domestic semiconductor industry[56]. In 1976, ITRI established an R&D partnership with RCA in the States focused on technology transfer and training for complementary metal oxide semiconductor (CMOS) design, process and testing[57]. Latterly, a *Science and Technology Advisory Group*, led by US semiconductor executives was established in 1979[58]. In parallel, during the 1970s a significant infrastructure effort, 'Ten Major Construction Projects', was undertaken to upgrade national utilities and transport infrastructure.

In 1980, under the direction of the Government, Hsinchu Science Park (HSP) was established. The creation of the park was the recommendation of a science and technology advisory group, under the aegis of Li, now Minister for Industry[59]. The first science park in Taiwan, it was established on military land. Its location was intended to take advantage of its proximity to ITRI, where the nascent domestic semiconductor industry was developing, as well two universities, the National Tsung Hua University (established in Hsinchu in 1956) and National Chiao Tung University (established in Hsinchu in 1958). Drawing on the EPZ model, the HSP was intended to be export-orientated. As with the EPZs, firms received incentives for locating at HSP, included lower rates of corporate tax[60].

Ten years later, HSP was home to over 120 companies, employing over 22,000 people and generating a total annual turnover of NT$65.6 billion[61]. One early occupant was United Microelectronics Corporation (UMC), Taiwan's first semiconductor company. UMC was established in 1980[62]. It was spun out of the ITRI RCA knowledge transfer team. It established its first fabrication plant at the HSP in 1982. Five years later, the Taiwan Semiconductor Manufacturing Corporation (TSMC) was established on the HSP. TSMC emerged from the publicly funded 'Very-Large-Scale Integrated Circuit (VLSI)' project, initiated in 1982 to develop a new generation of processing facilities[63]. It was established with public funding and investment from Dutch electronics company Philips. Following TSMC's establishment, the experimental foundry at ITRI was closed. Another ITRI spinout, semiconductor company Winbond, was also established on HSP in 1987.

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55. Wessner, Charles W. (ed.). 2013. 21st Century Manufacturing: The Role of the Manufacturing Extension Partnership Program, https://www.nap.edu/catalog/18448/21st-century-manufacturing-the-role-of-the-manufacturing-extension-partnership (accessed on 24 May 2020).
56. *Ibid.*
57. Chandra, Vandana. 2006 Technology, adaptation, and exports: How some developing countries got it right (English), http://documents.worldbank.org/curated/en/755111468335034109/Technology-adaptation-and-exports-How-some-developing-countries-got-it-right (accessed on 24 May 2020).
58. *Op. cit.* note 55
59. Yusuf, Shahid *et al* (ed). 2008 Growing Industrial Clusters in Asia: Serendipity and Science, http://documents.worldbank.org/curated/en/340261468001809027/text/439710PUB0Box310only109780821372135.txt (accessed on 24 May 2020).
60. *Ibid*.
61. *Ibid*.
62. UMC. 2020 UMC Overview, http://www.umc.com/English/about/index.asp (accessed on 24 May 2020).
63. *Op. cit.* note 59.

Growth of the Taiwanese semiconductor industry was rapid. The provision of foundry services by TSMC contributed to the direct and indirect creation of several integrated circuit design companies at Hsinchu. By 1993, the total sales revenue of companies based on HSP had reached NT$129 billion (approx. £3.44 billion), twice the 1990 value[64]. This growth served to attract the return of Taiwanese engineers that had been studying and working in the US. This, in turn, helped to build on the established links between companies in Hsinchu and America. In 1999, 40% of the companies located in the Hsinchu Science Park were founded by US-educated engineers[65].

The rapid growth at Hsinchu, led to the creation of two new science parks in Taiwan, in Tainan in the south in 1999 and Taichung in the centre in 2004. Also, HSP expanded twice between 1993 and 2004. In 2003, sales from semiconductor companies at HSP had grown to NT$563.3 billion (approx. £15.03 billion), around two-thirds of the total sales revenue of all companies at HSP[66]. Total employment at HSP in this year was over 100,000 people[67].

Since the mid-2000s, growth of the Hsinchu technology cluster has continued. Integrated circuit companies continue to dominate the HSP (34.2% of all companies), however, there are now also a considerable number of companies working in optoelectronics and biotechnology (17.5% and 18.1% respectively)[68].

Outcomes

The development of the Hsinchu cluster, with its focus on semiconductor technologies, has coincided with and contributed to, Taiwan's dramatic economic development – Taiwanese people were thirty times richer in 2016 than they were in 1950[69]. The manufacture of electronics and ICT products have become a key part of the economy[70]. The total turnover of all firms based on the three major science parks (Hsinchu, Central Taiwan, and Southern Taiwan) in 2018 was US$86.09 billion, approximately 15% of total GDP[71].

The total turnover of all firms at HSP in 2018 was US$35.67 billion, approximately 6% of GDP. In 2018, HSP hosted 512 companies, employing 153,503 people[72]. Smaller constituent science parks have now been established under HSP's banner to focus on emerging areas including biotechnology, optoelectronics, pharmaceuticals, photo electronics and biotechnology. The consolidated revenue of TSMC, who maintain an R&D centre and offices at HSP, reached US$34.20 billion in 2018[73]. The company now controls half the global foundry market[74].

64. *Ibid.*
65. Parker, Rachel. 2010 Evolution and change in industrial clusters: An analysis of Hsinchu and Sophia Antipolis, https://journals.sagepub.com/doi/pdf/10.1177/0969776409358244 (accessed on 24 May 2020).
66. *Op. cit.* note 59.
67. *Op. cit.* note 65.
68. Hsinchu Science Park. 2020 Hsinchu Science Park Bureau, Ministry of Science and Technology, https://www.sipa.gov.tw/english/ (accessed on 24 May 2020).
69. Roser, Max. 2020) Economic Growth, https://ourworldindata.org/economic-growth (accessed on 24 May 2020).
70. The official website of the Republic of China. 2020) Economy, https://www.taiwan.gov.tw/content_7.php (accessed on 24 May 2020).
71. *Ibid.*
72. Hsinchu Science Park. 2019 Hsinchu Science Park 2018, https://www.sipa.gov.tw/english/file/20190617135632.pdf (accessed on 24 May 2020).
73. TSMC. 2019 2018 Annual Report, https://www.tsmc.com/download/ir/annualReports/2018/english/index.html (accessed on 24 May 2020).
74. Hille, Kathrin. 2016 TSMC doubles earnings on bumper chip sales despite pandemic, https://www.ft.com/content/476b0f00-e11c-4925-91a3-fee639894819 (accessed on 24 May 2020).

ITRI too has grown considerably, from 400 staff in 1973, there are now 6,000 researchers working across the organisation. While its headquarters remain in Hsinchu, it now has offices across Taiwan as well as several global offices, intended to facilitate international collaboration. Since its establishment, the organisation has incubated more than 280 spinouts and holds over 28,000 patents. In 2018, its revenue was around £600 million, 45% was R&D income, while 55% was revenue from industrial services. It now focuses on a broad range of industrial research including biomedical technology, green energy, materials, mechanical and mechatronics, ICT and electronic and optoelectronic systems[75].

The success of Hsinchu technology cluster is evident in the region – the average disposable income is second only to Taipei[76].

Looking forward

The development of the Hsinchu technology cluster was built on the success of the semiconductor industry, which remains central to the regional and national economy. However, Taiwan is facing increasing competition, not least from mainland China which is seeking to develop its domestic semiconductor industry[77]. This poses a challenge both in terms of an increased number of competitors in the market as well as increasing local competition for skills – over 3,000 semiconductor engineers have left Taiwanese companies for mainland organisations[78]. While Taiwan is expected to remain a leader in this technology, this status will be increasingly challenged by external competition as well as changes within the technology itself[79].

Achieving long term continued growth will likely require further diversification. Long-term growth is made more likely by continued high levels of public and private investment in R&D – approximately 3% of GDP in 2015, with £9.95 billion from the private sector and £2.77 billion from the public sector[80].

75. ITRI. 2019 ITRI Introduction, https://www.itri.org.tw/english/ListStyle.aspx?DisplayStyle=18&SiteID=1&MmmID=1037333564027712341 (accessed on 24 May 2020).
76. Fulco, Matthew. 2019 What are Taiwan's Science Parks?, https://topics.amcham.com.tw/2019/03/what-are-taiwans-science-parks/ (accessed on 24 May 2020).
77. Ihara, Kensaku. 2019 Taiwan loses 3,000 chip engineers to 'Made in China 2025', https://asia.nikkei.com/Business/China-tech/Taiwan-loses-3-000-chip-engineers-to-Made-in-China-2025 (accessed on 24 May 2020).
78. Ihara, Kensaku. 2019 Taiwan loses 3,000 chip engineers to 'Made in China 2025', https://asia.nikkei.com/Business/China-tech/Taiwan-loses-3-000-chip-engineers-to-Made-in-China-2025 (accessed on 24 May 2020).
79. Soo, Zen *et al*. 2019 Taiwan became top chip manufacturer with US help. Can it stay there?, https://www.scmp.com/tech/tech-leaders-and-founders/article/3026766/taiwan-became-top-chip-manufacturer-us-help-can-it (accessed on 24 May 2020).
80. UK Science & Innovation Network. 2018 UK Science & Innovation Network Snapshot - Taiwan, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/723761/SIN_Taiwan_snapshot_November_2017__Updated_Contacts_.pdf (accessed on 24 May 2020).

Israel technology cluster

Introduction

Israel has gained the moniker of 'start-up nation'. Activity is concentrated in metropolitan Tel Aviv – including the affluent suburbs of Herzeliya, Ramat Gan and Ra'anana – and Haifa in the north (home to Matam Technology Park, Israel's first and largest high-tech business park), together with the second city of Jerusalem. Including some secondary areas, such as the corridor south from Tel Aviv to Be'er Sheva and Western Galilee, the cluster covers an area no larger than 6,000 square kilometres – half that of the extended Silicon Valley in the US[81].

Israel's R&D expenditure, at 4.58% of GDP, is far above the UK (1.67%), and the high-income country average (2.57%[82]). It has 8,250 R&D researchers per million people, compared to 4,377 in the UK and 4,196 in high-income countries[83].

Around 1,400 start-ups are created every year in Israel and some 800 shut down[84]. In total, there is roughly one start-up per 1,400 people. In comparison, France has 0.112 start-ups for every 1,400 people, Germany has 0.056, and the UK has 0.21[85]. This growth is not just a recent phenomenon. According to the IVC Research Center, 10,866 high-tech companies were established in the period 2010 to 2019, with 98 listed on the Nasdaq, and 369 accelerators and 24 incubators established.

Development

Israeli high-tech firms began to form in the 1960s, albeit at a slow pace[86]. ECI Telecom was founded in 1961, and Tadiran and Elron Electronics in 1962. The cluster truly emerged in the mid-1990s, as the rate of successful companies grew from 1-2 per year to 10-20. de Fontenay and Carmel attribute this to the emergence of 'specialised cluster intermediary services' such as venture capital and legal services, services which also had professional networks in the US, the major market for Israeli companies. Strong interpersonal networks and direct experience then allowed new firms to grow more quickly[87].

81. Carmel, Erran. *et al*. 2001 Israel's Silicon Wadi: The Forces behind cluster formation, https://siepr.stanford.edu/research/publications/israels-silicon-wadi-forces-behind-cluster-formation (accessed on 12 May 2020).
82. World Bank. 2020 Research and development expenditure (% of GDP), https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS (accessed on 12 May 2020).
83. World Bank. 2020 Researchers in R&D (per million people), https://data.worldbank.org/indicator/SP.POP.SCIE.RD.P6?locations=IL-GB-XD (accessed on 12 May 2020)
84. Solomon, Shoshanna. 2017 Start-up Nation has grown into Tech Nation, Intel Israel R&D chief says, https://www.timesofisrael.com/startup-nation-has-grown-into-tech-nation-intel-israel-rd-chief-says/ (accessed on 12 May 2020).
85. Bordo, Matan. 2018 Israeli Tech's Identity Crisis: Startup Nation or Scale Up Nation?, https://www.forbes.com/sites/startupnationcentral/2018/05/14/israeli-techs-identity-crisis-startup-nation-or-scale-up-nation/#67023dd6ef48 (accessed on 12 May 2020).
86. *Op. cit.* note 81.
87. *Ibid.*

Image
Matam High-Tech park, Haifa, Israel. © Zvi Roger – Haifa Municipality, via Wikimedia commons CC BY 3.0.

Global telecommunications and internet booms in the 1990s increased demand and led to several high-profile acquisitions of Israeli companies[88]. Shifts in the computer industry from hardware to software products greatly benefited Israel, particularly owing to the demand from businesses for security tools – several of which had been well-tested within Israeli military communications networks[89]. Finally, the 1993 Oslo accords with the Palestinians encouraged large companies such as Cisco, Motorola, IBM, Microsoft and Hewlett-Packard to invest heavily in R&D centres in Israel, helping to build international networks, expand employment opportunities and develop skills[90].

Government interventions have directly stimulated the Israeli technology cluster, with the state nurturing the development of a venture capital industry. Yozma (Hebrew for 'initiative') began in 1993 with US$100 million and established 10 venture capital funds to attract foreign direct investment into Israel. Investors were offered matched funding at the rate of two dollars from the government for every dollar committed by a foreign investor. Equally generous was the option of buying out the government's stake in the fund after five years. The fund has grown to manage billions of dollars of capital today[91].

88. Haynes, Caroline *et al*. 2014 Magnet Cities, https://home.kpmg/uk/en/home/insights/2014/07/magnet-cities.html (accessed on 12 May 2020).
89. *Op. cit.* note 81.
90. Devi, Sharmila. 2007 Business as usual, https://www.ft.com/content/090e5dd2-e88e-11db-b2c3-000b5df10621 (accessed on 12 May 2020).
91. *Op. cit.* note 88.

Other important initiatives include the Office of the Chief Scientist (now Israel Innovation Authority) R&D Development Fund, which gives new R&D facilities access to interest-free loans to match private investment, and the Israel-US Binational Industrial Research and Development Foundation (BIRD) fund, financed by both governments. BIRD 'played matchmaker' between Israeli companies with innovative technology and US companies who could distribute and market the product. Although the financial incentives were helpful, the largest impact was to teach young Israeli companies how to do business in the US[92]. The state has also reduced bureaucracy, simplified tax regulations, and established incubators[93].

Finally, two further factors have enabled cluster growth. The first is the influence of the unique Israeli military culture, common in Israeli businesses because of compulsive military service (for at least two years from the age of 18). The Israel Defence Forces have an unusually flat hierarchy, leading to informal communication with superiors (and the willingness to challenge authority), great flexibility, the development of strong leadership skills, and experience of shouldering considerable responsibility at a young age[94]. The strong networks formed in the military – often with people from different backgrounds – are then maintained through reserve duty for many years following military service[95]. Alumni who met whilst working in the elite military units (particularly in intelligence) have spawned many high-tech companies, and graduates from these units are often the recruitment targets of major US technology companies[96].

The second contributory factor was a large stock of human capital. Levels of education and technical skills are high, supported by world-class universities such as the Israel Institute of Technology (called the Technion) and the Weizmann Institute of Science. But the Israeli government's open immigration policy towards Jewish people across the world has also provided a significant inflow of talent. When the US tightened immigration in the 1990s, Israel saw a dramatic increase in immigration of often highly-educated immigrants from former Soviet Union nations – in ten years the population grew by 800,000 or one fifth; the number of engineers in Tel Aviv doubled. Given the traditional strengths of Soviet Union countries in theoretical sciences, Israel became 'a superpower in mathematics', as well as gaining knowledge of proprietary technologies and different methodologies[97]. These enabling factors helped the development of the Israeli technology cluster.

Outcomes

By the late 1990s, the Israeli technology cluster was internationally connected and strongly entrepreneurial, based on deep stocks of human capital and local knowledge. The source of this innovation was the commercialisation of military technology and university R&D, supported by flows of skilled workers and public sector intervention to promote investment and generate capital[98].

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92. Senor, Dan *et al*. 2009 Start-up nation: The story of Israel's economic miracle, https://www.penguinrandomhouse.ca/books/164015/start-up-nation-by-dan-senor-and-saul-singer/9780771079665 (accessed on 12 May 2020).
93. *Op. cit.* note 81.
94. *Op. cit.* note 92.
95. *Op. cit.* note 90.
96. *Op. cit.* note 88.
97. *Op. cit.* note 81.
98. Roper, Stephen *et al*. 2005 Wireless valley, silicon wadi and digital island––Helsinki, Tel Aviv and Dublin and the ICT global production network, https://www.sciencedirect.com/science/article/abs/pii/S0016718504000880 (accessed on 12 May 2020).

ICT services now form over 45% of Israel's service exports, compared to 7% for the UK, and 9.5% for high-income countries as a whole[99].

Professional ties with other clusters, such as Silicon Valley, are strong and aided by the diaspora concentrated in New York and Los Angeles. Concerns over brain drain, as young Israelis look to study and work abroad, are countered by new networks formed and the return of expatriates – often many years later – to set up regional offices or to champion investment and R&D centres in Israel[100].

A mature venture capital industry has emerged in Israel. More than 430 professional investors (including venture capital firms, private equity firms and incubators) have a permanent presence in Israel; just under a quarter of these are non-Israeli. Nearly 1,500 investors, representing more than 30 countries, invested in Israeli companies during 2018[101]. Since 2010, capital raising by Israeli tech companies has risen by 400% and the number of deals by 64%[102].

Looking forward

The Israeli technology sector continues to perform strongly. In the third quarter alone of 2019, Israeli start-ups raised $4.68 billion in venture funding equivalent to all funding raised in 2018[103].

There is concern that start-up founders are too focused on buy-outs from overseas companies or public listings, instead of growing large businesses[104]. Connected to this are perennial fears of brain drain and an exodus of talent to the US[105]. These fears are heightened by a shortage of skilled software engineers, with five jobs for every applicant in the sector. Efforts to bridge the gap include alternative training programs such as tech boot camps and boosting recruitment of women and Arab and ultra-Orthodox Jewish minorities, who are all under-represented in the sector[106].

99. World Bank. 2020 ICT service exports (% of service exports, BoP), https://data.worldbank.org/indicator/BX.GSR.CCIS.ZS (accessed on 12 May 2020).

100. *Op. cit.* note 81.

101. Start-Up National Central: Finder Insights Series. 2019 The State of the Israeli ecosystem in 2018, http://mlp.startupnationcentral.org/rs/663-SRH-472/images/Start-Up%20Nation%20Central%20Annual%20Report%202019.pdf (accessed on 12 May 2020).

102. IVC. 2020) IVC Annual Israeli Tech Review, https://www.ivc-online.com/Portals/0/RC/Magazine%20&%20YB/IVC_ANNUAL_ISRAELI_TECH_REVIEW_FEB_2020/mobile/index.html#p=4 (accessed on 12 May 2020)).

103. Bino, Eyal. 2019 5 Bold Predictions For Israeli Tech in 2020), https://www.forbes.com/sites/eyalbino/2020/12/31/5-bold-predictions-for-israeli-tech-in-2020/#5a97200e413f (accessed on 12 May 2020).

104. *Op. cit.* note 88.

105. Schwartz, Yardena. 2018 More Israelis are moving to the U.S. – and staying for good, https://www.newsweek.com/2018/05/18/israel-brain-drain-technology-startup-nation-religion-palestinians-economy-919477.html (accessed on 12 May 2020).

106. Start-up Nation. 2020 Five ways to tackle the human capital shortage in Israel's high-tech industry, https://blog.startupnationcentral.org/general/israel-high-tech-human-capital-shortage/ (accessed on 12 May 2020).

Pittsburgh life sciences cluster

Introduction

Pittsburgh includes clusters with some areas of overlap. The Pittsburgh Innovation District lists these as life sciences and digital health, advanced manufacturing, and AI and robotics, whereas the Brookings Institution identifies manufacturing, technology, and health care as key clusters[107]. These industries have grown by 8.4%, nearly double Pittsburgh's private-sector growth rate, since the end of the recession in the early 2010s[108].

The Oakland district is the academic and healthcare centre of Pittsburgh and is an example of two much-vaunted developments: an innovation district home to a dense, walkable hub of economic activity for research and entrepreneurship, and a shift from heavy industry to 'eds and meds', with the knowledge-rich ecosystem that accompanies universities, large hospitals and their spinoffs and spillovers[109]. Oakland represents 3% of the city's land area, 10% of residents, 29% of jobs, and over a third of the state of Pennsylvania's university research output[110]. Challenges remain in ensuring inclusive growth in neighbouring districts (which have some of the highest rates of long-term unemployment and poverty in the city), connecting communities to new opportunities, and addressing regional inequalities.

Pittsburgh's performance is often framed against the collapse of the steel industry in the city in the 1980s when the unemployment rate in the city hit 18%. Before the collapse, manufacturing represented more than a quarter of all employment in Pittsburgh. Manufacturing accounts for under 10% of employment. More people work in Pittsburgh's health sector today than in the steel industry at its highest point[111].

Development

By 1983, Pittsburgh – seen as the industrial powerhouse of the US – was in an economic breakdown. The Pittsburgh Press newspaper described it as a tide of change: 'town by town, factory by factory, job by job[112]'. Three-quarters of Pittsburgh's steelmaking capacity and 130,000 manufacturing jobs were lost, and tens of thousands of residents moved away – with knock-on effects for the businesses and services which remained[113].

In the following decades, the economy shifted from low- and moderate-value production to technology-driven services and high-value advanced manufacturing. This shift was led by a focus on innovation, driven by federally-funded research at Carnegie Mellon University and the University of Pittsburgh[114].

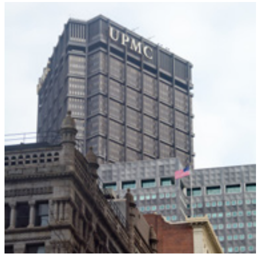

Image
University of Pittsburgh Medical Center tower.
© ErikaMitchell.

107. Andes, Scott *et al*. 2017 Capturing the next economy: Pittsburgh's rise as a global innovation city, https://www.brookings.edu/wp-content/uploads/2017/09/pittsburgh_full.pdf (accessed on 12 May 2020).
108. *Ibid.*
109. Madison, Michael. 2011 Contrasts in innovation: Pittsburgh then and now, https://ideas.repec.org/p/osf/lawarx/e64rs.html (accessed on 12 May 2020).
110. *Op. cit.* note 107.
111. *Op. cit.* note 109.
112. Toland, Brian. 2012 In desperate 1983, there was nowhere for Pittsburgh's economy to go but up, https://www.post-gazette.com/business/businessnews/2012/12/23/In-desperate-1983-there-was-nowhere-for-Pittsburgh-s-economy-to-go-but-up/stories/201212230258 (accessed on 12 May 2020).
113. *Op. cit.* note 107.
114. Gallagher, Patrick. 2017 Pittsburgh myth, Paris reality, https://science.sciencemag.org/content/356/6343/1103 (accessed on 12 May 2020).

Important investments were made in three areas in the 1950s[115]. The first was a partnership known as 'Renaissance I' between local government leaders and Pittsburgh's business community (under the banner of the Allegheny Conference). The aim was to improve the quality of life in the city and address the region's environmental and infrastructure issues. Real estate development was channelled through public authorities, deserted train sheds were converted to house and offices, cultural attractions were built, and transport and sanitation improved.

The second investment was a donation of $50 million from the local Mellon family to the University of Pittsburgh to build and run a new medical school. The creation of a world-class medical research institution set a foundation for the region's biomedical research strengths today. Funding from philanthropic foundations has ensured the survival of much of the city's cultural infrastructure from the Symphony Orchestra to community arts organisations – an essential ingredient in creating an environment for attracting and retaining skilled workers. More recently, foundations in the city have tended to view economic development through technological innovation as a core part of their social mission. Philanthropic investment has, for example, helped transfer robotic and automation technology from the lab to the city for real-world testing, and was central to starting programmes of work on machine learning, computational finance, and robotics at Carnegie Mellon University[116].

As unemployment soared in the 1970s, the heads of Carnegie Mellon University and the University of Pittsburgh – historically competitors – decided to coordinate efforts to diversify Pittsburgh's economy and drive research and development in the city[117]. In 1978, Carnegie Mellon University, led by Richard Cyert, established the Robotics Institute with corporate funding and planted the seed for the city's expertise in this area (the CMU Robotics Institute also became the first in the world to offer a PhD in robotics[118]). The investments made by the University and local leaders in new technologies in Pittsburgh – others included biotech and computing – have been described as 'sensing activities', speculative investments that are the first stage of an innovation ecosystem (with no guarantee they will pay off), and which 'assess internal and external signals about scientific and technological developments that hold promise for the future, then ensure that sufficient financial and faculty resources are available for exploring the most attractive possibilities[119]'.

In 1986, with University of Pittsburgh Chancellor Wesley Posvar's guidance, all of the city's hospitals, teaching hospitals and research facilities were brought together under one not-for-profit roof – known today as UPMC. And as Carnegie Mellon University sought out the best researchers to relocate in Pittsburgh, the University of Pittsburgh persuaded medical experts to join, including pioneers of organ transplantation – helping to establish the city as a world-leading centre in this area[120].

115. *Op. cit.* note 109.

116. *Op. cit.* note 107.

117. *Op. cit.* note 88.

118. *Ibid.*

119. Heaton, Sohvi *et al*. 2019 Universities and innovation ecosystems: a dynamic capabilities perspective, https://academic.oup.com/icc/article-abstract/28/4/921/5526923?redirectedFrom=fulltext (accessed on 12 May 2020).

120. *Op. cit.* note 88.

The universities have continued to play an important role in shaping Pittsburgh's research and innovation clusters. When Jared Cohon stepped down as Carnegie Mellon University president in 2013, he identified three key ways the institution helped Pittsburgh's economic shift: by making it easier for professors to start new companies by changing the technology transfer policy, by collaborating with the University of Pittsburgh to support start-ups, and by building the Robert Mehrabian Collaborative Innovation Centre[121]. This centre opened in 2005 and was funded by the state, university and private money, allowing companies and researchers to work collaboratively.

State and federal governments have also played an important role. Both provided grants to research universities and seed funding to entrepreneurs in technology-related fields.

Pittsburgh's reinvention required the city's leadership to "think like a system and act like an entrepreneur" – taking stock of assets, cultivating talent, and maintaining a good place to live, whilst taking risks, seizing opportunities and being flexible[122]. Tom Murphy, a state representative who later became mayor of Pittsburgh, is regarded as one such leader. Recognising and supporting the role of universities in a post-steel Pittsburgh, he introduced the Ben Franklin Technology Partnership in 1983, dedicated to advancing early-stage start-up businesses and the commercialisation of technologies – since described as a state programme run like a venture capital firm[123].

After becoming mayor in 1994, Murphy developed more than 25 miles of new trails alongside the river and urban green space and cleaned up more than 1,000 acres of abandoned industrial land[124]. In more recent years, the city has improved its food and art culture, helping to attract skilled workers[125]. This, combined with a consistently low cost of living, has helped Pittsburgh's economic transition[126].

Outcomes

Michael J Madison, a Professor at the University of Pittsburgh, describes the city's revitalisation as being less about the 'grit' and character of Pittsburghers (a popular narrative to explain the transition) and more about having economic diversification thrust upon it[127]. By building on strong research and innovation assets – UPMC, the University of Pittsburgh, and Carnegie Mellon University – the city has managed to excel in knowledge production. Pittsburgh's education and technology sectors account for 80% of the high-wage jobs in the city[128]. Overall, the technology sector accounts for a third of annual payroll in the Pittsburgh region, helping to retain highly educated young people[129].
In 2016 the region's university research and development spending per capita was nearly two and a half times the national average[130].

121. *Op. cit.* note 119.
122. Katz, Bruce *et al*. 2018 How the Once-Struggling Pittsburgh Is Reinventing Itself as an Innovation Hub, https://nextcity.org/daily/entry/how-the-once-struggling-pittsburgh-is-reinventing-itself-as-innovation-hub (accessed on 12 May 2020).
123. *Op. cit.* note 88.
124. The Economist. 2011 Smaller is more beautiful, https://www.economist.com/united-states/2011/10/22/smaller-is-more-beautiful (accessed on 12 May 2020).
125. *Op. cit.* note 107.
126. *Op. cit.* note 109.
127. *Ibid.*
128. *Op. cit.* note 119.
129. Holstein, Adora *et al*. 2017 Economic Analysis Of Public Support For Tech Startups: A Case Study Of Pittsburgh, https://search.proquest.com/openview/a19ad9f3bf237171584ba45749e1806e/1?pq-origsite=gscholar&cbl=2030637 (accessed on 12 May 2020).
130. *Op. cit.* note 107.

There are still threads connecting modern Pittsburgh to the rich legacy of manufacturing in the city. The advanced manufacturing clusters in the region are highly specialised: automation and industrial machinery, and metals and metal processing each have more than two times the national employment concentration. New clusters have formed around these industries as technology companies seek access to top engineering and computer science talent[131].

However, the acceleration of scientific and technical activity and global expertise headquartered in the city has not translated locally into broad-based growth outside the clusters, and in the neighbourhoods in which they are sited[132]. As Madison puts it, "steel money was sucked out of one part of the Pittsburgh region; new money is largely being injected elsewhere"[133]. The risk is that, without new jobs being created at all skill levels, spatial inequality in the region will increase. The Brookings Institution recommends in particular that the Oakland innovation district needs to be marketed and better connected to the regional economy, with better integration with nearby employment centres[134].

Looking forward

A 2017 benchmarking report examined the prospects of Pittsburgh's life sciences cluster, and found opportunities for developing new solutions and innovations at the intersection with other clusters – automation, robotics, and healthcare – and with other areas of expertise – biomedicine at the University of Pittsburgh and computer science at Carnegie Mellon University[135]. The blurring and crossover of disciplinary boundaries extends to collaboration with the private sector. The report gives the example of UPMC partnering with IBM Watson to form Pensiamo, a Pittsburgh-based start-up using cognitive analytics to improve supply chain performance in hospitals[136].

Pittsburgh's clusters face several challenges. Commercialisation is lagging, in particular in life science firms, which often take longer to develop. Although investment trends are improving, the region has less venture capital funding than other US innovation hubs[137]. Connected to this is a low rate of high-growth start-ups. One contributing factor is the need for more corporate partners (a barrier to recruiting talent to start-ups is the lack of backup employment options if the local start-up does not succeed – a truly effective cluster, by definition, offers choice[138]). And finally, ongoing challenges remain over continuing to build links between the research being conducted in universities and the strengths of industry, and ensuring a pipeline of skills to meet future workforce needs: fundamental concerns that remain constant even for well-established clusters[139].

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131. *Ibid*.
132. *Op. cit.* note 122.
133. *Op. cit.* note 109.
134. *Op. cit.* note 107.
135. Fourth Economy in Collaboration with Warner Advisors. 2017 Pittsburgh Region Life Sciences Benchmarking & Opportunities Analysis, https://static1.squarespace.com/static/58d536dc440243d1c7bbb4a7/t/59231f943a041114fd79fad3/1495474075938/Pitt+Life+Sciences+Benchmarking+and+Opportunties+Analysis+for+Website.pdf (accessed on 12 May 2020).
136. Pensiamo, 2020 https://www.pensiamoinc.com/ (accessed on 12 May 2020).
137. *Op. cit.* note 107.
138. *Op. cit.* note 135.
139. *Op. cit.* note 107.

San Diego communications cluster

Introduction

San Diego has become closely associated with one company – Qualcomm – and the companies that have emerged from it and its precursor Linkabit. The growth of the communications cluster since the 1970s supported the expansion of the local research-intensive university, University of California San Diego.

At the outset of the twentieth century, the city was geographically isolated, with limited access to water to support agriculture, no extractable natural resources, no major transportation links and slow population growth. The transformation that has occurred is the product of a collaboration between national and local government, the local research base and the region's industry[140].

Development

In 1903, members of the Scripps family and other community representatives established the Marine Biological Association of San Diego later building a laboratory. The laboratory was acquired by the University of California in 1912 and renamed the Scripps Institution for Biological Research (later changed to the Scripps Institution of Oceanography). In 1938, the Scripps Institution of Oceanography was designated as a University of California Division of War Research - part of an initiative led by Vannevar Bush, Director of the Office of Scientific Research and Development during WWII to "mobilize universities to conduct basic and applied research developing technology for the war effort"[141]. Building on this activity, the Naval Electronics Lab was established in Point Loma San Diego in 1945. The Navy Electronics Lab received considerable investment from the Federal Government throughout the 1940s and 1950s and served to attract military contractors to the city including General Dynamics.

Partially in response to the growing need for a skilled workforce to carry out R&D activity, local business leaders and researchers began to advocate for the establishment of a new University of California campus in San Diego. General Atomics, a spinoff of General Dynamics, pledged $1 million to support a new institution. In 1959 a campus was approved. Henry G. Booker, who had worked for the Telecommunications Research Establishment in England during WWII, was recruited in the 1960s from Cornell University to build a physics and information sciences programme at the new university. Booker then hired Irwin Jacobs from MIT to join UC San Diego in 1966 as a faculty member in the Applied Electrophysics Department.

In 1968 Irwin Jacobs, who had begun to do consultancy work for the Navy while at UC San Diego, founded Linkabit with two faculty members from UC Los Angeles, Leonard Kleinrock and Andrew Viterbi. Initially based in Los Angeles, the company moved to Sorrento Valley in San Diego in 1970. Early customers of the company included the Naval Electronics Lab, Defense Advanced Research Projects Agency (DARPA) and NASA – for whom the company supported communications for deep space missions. The company grew throughout the 1970s through continued military contracts. In 1980 the company was acquired by M/A-COM for $25 million. Irwin Jacobs and Andrew Viterbi left the company in 1985 and established Qualcomm with other former colleagues from Linkabit. In the 1990s the company developed new transmission technology for cellular phones – CDMA (Code Division Multiple Access) – which provided "simultaneous access to a multitude of users, with less interference and greater security for voice

140. Walshok, Mary. 2019 Presentation to the National Academies

141. Kenney, Martin *et al*. 2014. Public universities and regional growth: insights from the University of California, https://stanford.idm.oclc.org/login?url=http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&AN=778906 (accessed on 16 January 2020).

and data"[142]. The technology was not initially widely adopted but the approach was incorporated into major 3G cellular standards, cdma2000 and W-CDMA. "By 2000, there were 50 million CDMA supported cell phones in the world"[143]. In 1999 Qualcomm entered the Fortune 5000 with annual revenues over $3 billion. At this point, the company employed 7,000 people.

Linkabit and latterly Qualcomm exist at the core of San Diego's communications cluster. Many of the other companies that have grown around these 'anchor institutions' have been created by former colleagues of one or both of these organisations[144], some of which have since been acquired by larger businesses. Leap Wireless was established in 1998 as a corporate spinoff. It was later acquired by AT&T for $1.2 billion in 2013. Viasat was established in 1986 by former Linkabit employees, Mark Dankberg, Steven Hart and Mark Miller. In 2019, the company had annual revenue of $2.1 billion[145]. Alongside the development of local industry, the growth of the cluster has encouraged others to locate in the region including Sony in the 1990s and Nokia in the early 2000s.

UC San Diego has grown in tandem with the development of the communications cluster. The School of Engineering has grown since the 1960s as a consequence of the demand for advanced skills as well as more direct contributions including endowments from Qualcomm founders Irwin Jacobs and Andrew Viterbi. A Centre for Wireless Communications was established in 1995. The University founded the CONNECT initiative in 1986. It began as an internal technology transfer office and became a start-up accelerator when the university joined with the regional economic development corporation and local businesses.

Outcomes

In 2016, the GDP for the US was $17,688 billion, $2,500 billion for California and $203 billion for San Diego[146]. The innovation economy accounted for approximately $55 billion of San Diego's total GDP[147]. San Diego's innovation economy includes the communications cluster, other ICT industries as well as life sciences; aerospace, navigation & marine; and technology consulting services.

142. University of Southern California. 2020 About Andrew J Viterbi, https://viterbischool.usc.edu/about-andrew-viterbi/ (accessed on 16 January 2020).

143. *Ibid.*

144. Dennis, Martha G. 2009 Linkabit Genealogy, https://libraries.ucsd.edu/sdta/_files/bios/docs/dennis-martha-linkabit-tree.pdf (accessed on 16 January 2020).

145. Viasat. 2019 Viasat Announces Fourth Quarter and Fiscal Year 2019 Results, http://investors.viasat.com/news-releases/news-release-details/viasat-announces-fourth-quarter-and-fiscal-year-2019-results (accessed on 16 January 2020).

146. Bureau of Economic Analysis. 2019 Local Area Gross Domestic Product, 2018, https://www.bea.gov/system/files/2019-12/lagdp1219.pdf (accessed on 16 January 2020).

147. CONNECT. 2017 San Diego Innovation Report 2016, https://www.connect.org/wp-content/uploads/2019/12/2016_INNOVATION_REPORT_FINAL.pdf (accessed on 16 January 2020).

The innovation economy employs 150,660 people – 11% of the total workforce, an increase of over 10,000 since 2008, though an increase of 15,000 since 2009. The average salary for a job in the innovation economy is $110,700 compared with $51,500 for the rest of the economy in San Diego. Within this, the average wage is highest in the biotechnology and pharmaceutical industries, though communications equipment manufacturing, software and computer & electronics are second, third and fourth respectively with average wages of $130,800, $109,833 and $108,433[148].

San Diego's research institutions have an economic impact of $4.6 billion and employ around 37,000 people a year including 111 members of the National Academies of Science and 2,600 postdocs. In 2016, these institutions received $1.15 billion in federal grant funding, of which around $550 million went to UC San Diego.

In 2019, UC San Diego received $1.35 billion in research funding[149]. $803 million of this came from federal agencies including the National Institutes of Health (NIH), the National Science Foundation and the Department of Defense. Contracts and grants from industry sponsors accounted for $205 million. The university currently has an enrolment of 36,324. It supports 74,071 jobs throughout the San Diego County and adds $4.6 billion per year to the regional economy[150].

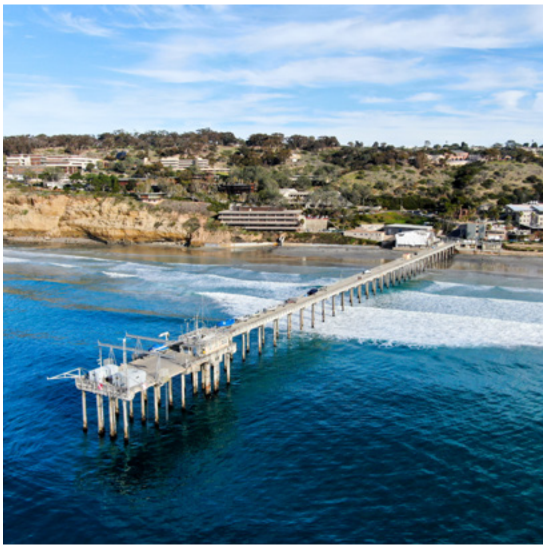

Image
Aerial view of the Scripps Pier institute of oceanography, La Jolla, San Diego, California. © Thomas De Wever.

Looking forward

The presence of the Navy in San Diego created the conditions for the creation of UC San Diego and the companies that emerged from it. Defence remains an important part of the local economy alongside the broader innovation economy. Job growth in the innovation economy remains steady and there are a growing number of start-ups each year.

Qualcomm remains central to the economy. It employs 13,000 people with an average salary of around $105,000. In 2018 the company generated "about $7.4 billion or 3.6% of the region's annual economic output"[151]. The company has faced financial and legal challenges and was subject to a proposed takeover by Singaporean based communications company Broadcom that was blocked in 2018 on national security grounds. It is hoped that the transition to 5G will provide growth for the company and the region.

148. *Ibid.*

149. UC San Diego. 2019 UC San Diego Breaks Record with $1.35 billion in Research Funding, https://ucsdnews.ucsd.edu/feature/uc-san-diego-breaks-record-with-1.35b-in-research-funding (accessed on 16 January 2020).

150. UC San Diego. 2019 UCSD Economic Impact Brochure 2019, https://ucpa.ucsd.edu/images/uploads/UCSD-Economic-Impact-Brochure-2019.pdf (accessed on 16 January 2020).

151. *Ibid.*

Sheffield advanced manufacturing cluster

Introduction

Sheffield has emerged as a centre of advanced manufacturing expertise in the UK. At its core is the University of Sheffield's Advanced Manufacturing Research Centre (AMRC) and the Advanced Manufacturing Park (AMP).

The UK was the largest producer of iron and steel until the mid-eighteenth century[152] and the industry remained significant well into the twentieth century. Sheffield was a thriving industrial economy where important innovations took place - stainless steel was invented in the city in 1913.

Following the second world war the UK steel industry, facing increasing global competition, went through rounds of nationalisation and privatisation[153]. Nationally, the industry began to shrink, with total employment in the steel industry falling from 323,000 in 1971 to around 60,000 in the mid-1990s[154]. In Sheffield, this decline brought a massive reduction in the number of manufacturing jobs and a corresponding increase in unemployment – from 1978 to 1984 unemployment rose from 4% to 16%, while employment in manufacturing fell from 50% of the workforce in 1971 to 24% of a reduced workforce in 1984[155]. Sheffield also suffered from the decline of the coal industry during this period and was at the centre of the 1984-1985 miner's strike.

Development

Professor Keith Ridgway joined the University of Sheffield from industry in 1988 as a lecturer, becoming a Professor of Design and Manufacturer in 1997. At that point, the University – itself partially the product of the local steel industry – was already an established research centre for engineering. In the 1996 Research Assessment Exercise, it was recognised as achieving research quality that "equates to attainable levels of international excellence in some sub-areas of activity and to attainable levels of national excellence in virtually all others"[156]. Professor Ridgway began to work with Adrian Allen of Technicut[157], a local manufacturer of rotary cutting[158], in 1998. They contacted American aerospace company Boeing who were seeking to establish research centres.

152. Financial Times. 2019 The UK needs to decide if British Steel is strategic, https://www.ft.com/content/540b596c-053f-11ea-a984-fbbacad9e7dd (accessed on 24 May 2020).
153. Groom, Brian. 2016 The long, slow decline of the British steel industry, https://www.ft.com/content/05c2f8b2-f7e4-11e5-96db-fc683b5e52db (accessed on 24 May 2020).
154. Office for National Statistics. 2016 Updated: The British steel industry since the 1970s, https://www.ons.gov.uk/economy/economicoutputandproductivity/output/articles/updatedthebritishsteelindustrysincethe1970s/2016-01-18 (accessed on 24 May 2020).
155. Lane, Laura *et al*. 2016 Sheffield City Story, http://eprints.lse.ac.uk/67849/1/casereport103.pdf (accessed on 24 May 2020).
156. Research Assessment Exercise. 1996 Research Assessment Exercise 1996, http://www.rae.ac.uk/1996/c1_96.html#annexc (accessed on 24 May 2020).
157. Breach, Anthony. 2019 Parks and innovation: Lessons from Sheffield's Advanced Manufacturing Park, https://www.centreforcities.org/publication/parks-and-innovation/ (accessed on 24 May 2020).
158. Technicut. 2020 About us, https://www.technicut.co.uk/ (accessed on 24 May 2020).

The South Yorkshire Centre of Excellence was established in 2001 with £15 million of funding from the University, Boeing and additional support from regional development agency Yorkshire Forward and the European Union[159]. It was latterly rebranded as the Advanced Manufacturing Centre (AMRC). The AMRC is focused on applied research intended to improve industrial processes, develop new tools and techniques and illustrate how new technologies can be best used by industry. It works to optimise production, but is not itself, primarily a site for production.

In 2003, the AMRC became the anchor tenant of an industrial park in Catcliffe, Rotherham[160] 8km from Sheffield city centre on the former site of the Orgreave Colliery, the setting of a dramatic confrontation between protestors and the police during the 1980s[161]. The site became the Advance Manufacturing Park in 2006. The Advanced Manufacturing Park Technology Centre opened in the same year, providing office space and workshops for small, high-growth companies working in advanced materials and manufacturing.

The AMRC Rolls-Royce Factory of the Future opened on the AMP in 2008 with £15 million of funding from industry partners and the European Regional Development Fund. The facility houses conference, laboratory, office and workshop space, with a focus on machining research. It was extended in 2012, growing from 4,654 to 6,400 square metres.

In 2012, the Nuclear Advanced Manufacturing Research Centre (Nuclear AMRC) was officially opened at the AMP, having been announced in 2009 by then Business Secretary Lord Mandelson. A partnership of the University of Sheffield and the University of Manchester with Rolls Royce, the Nuclear AMRC received £15 million of initial funding from the Department for Business, Innovation and Skills and £10 million of initial funding from the regional development agency, Yorkshire Forward[162].

159. University of Sheffield. 2003 World's largest aerospace company invests on Advanced Manufacturing Park, https://www.sheffield.ac.uk/news/nr/141-1.174760 (accessed on 24 May 2020).

160. AMRC. 2020 A world-class centre for advanced manufacturing, https://www.amrc.co.uk/files/document/102/1578487027_Member_brochure_DL.pdf (accessed on 24 May 2020).

161. Gapper, John. 2016 Orgreave revisited, https://www.ft.com/content/67da1790-3120-11e6-ad39-3fee5ffe5b5b (accessed on 24 May 2020).

162. Nuclear AMRC. 2009 Lord Mandelson announces £25 million Nuclear AMRC, https://www.namrc.co.uk/centre/announcementnuclearamrc/ (accessed on 24 May 2020).

Image
Advanced Manufacturing Park, Sheffield, United Kingdom. © Jeanette Teare / Alamy Stock Photo.

In 2011, both the AMRC and the Nuclear AMRC became part of the High Value Manufacturing Catapult, the first of the Catapult Network - a series of Technology and Innovation Centres launched following a 2010 report by entrepeneur Dr Hermann Hauser[163]. This status has led to additional public funding for both Centres. In 2018, as part of a larger announcement, it was announced that both centres would receive a combined total of £127 million of Government funding over five years[164].

The first cohort of 140 apprentices began training at the AMRC Training Centre in October 2013[165]. The Centre, which provides training courses and apprenticeships, was supported by funding from the Regional Growth Fund, the European Regional Development Fund and the European Social Fund.

The period from 2014 onwards has seen considerable further growth of the AMRC, with the expansions of existing facilities on the AMP and the creation of the Medical AMRC in 2014. The AMRC also expanded into the adjacent Sheffield Business Park, with the launch of Factory 2050, a 'reconfigurable factory' facility in December 2015[166].

In 2018, Boeing, a co-founder of the AMRC, opened its first European production facility at the Sheffield Business Park. In the same year, automotive company McLaren opened a Composites Technology Centre at the AMP.

163. Hauser, Hermann. 2010 The Current and Future Role of Technology and Innovation Centres in the UK, https://webarchive.nationalarchives.gov.uk/20121205223008/http:/www.bis.gov.uk/assets/biscore/innovation/docs/10-843-role-of-technology-innovation-centres-hauser-review (accessed on 24 May 2020).

164. University of Sheffield. 2018 Five-year funding confirmed for University's High Value Manufacturing Catapult centres, https://www.sheffield.ac.uk/news/nr/high-value-manufacturing-catapult-funding-armc-nuclear-1.797121 (accessed on 24 May 2020).

165. AMRC Training Centre. 2020 Demand for apprenticeships at AMRC Training Centre soars, https://www.amrctraining.co.uk/show-news-item/demand-for-apprenticeships-at-amrc-training-centre-soars (accessed on 24 May 2020).

166. AMRC. 2015 AMRC launches cutting edge Factory 2050 advanced manufacturing research facility in Sheffield, https://www.amrc.co.uk/news/amrc-launches-cutting-edge-factory-2050-advanced-manufacturing-research-facility-in-sheffield (accessed on 24 May 2020).

The AMP and Sheffield Business Park is described as the centre of Sheffield's Advanced Manufacturing Innovation District[167], now part of the Global Innovation Corridor – a locally-led initiative to attract greater investment into the region[168].

The growth of the advanced manufacturing cluster has taken place in the wider context of the development of the South Yorkshire region. In 2000, Objective One funding for the region was agreed by the European Union[169]. Objective One funding is intended to 'promote the development and structural adjustment of the poorest regions whose economies lag behind and achieve less than 75% of the European average per capita GDP[170].' The programme drew from the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the European Agricultural Guidance and Guarantee Fund (EAGGF). The region received £820 million from the EU during 2000 – 2008 with a further £1.38 billion leveraged from the UK Government and the private sector[171]. Further support from the European Union, UK Government and private sector have been leveraged since 2008. In addition to providing direct support for the advanced manufacturing cluster, other results of this funding include the regeneration of the city centre, improved transport infrastructure and investment in a range of skills and business support projects[172]. Sheffield Hallam University and Sheffield College have played key roles in these wider initiatives.

Outcomes

Since the early 1990s, Sheffield has seen considerable, though interrupted, growth. From 1998 to 2018, the population of Sheffield City Region (the Sheffield City Region includes Barnsley, Doncaster, Rotherham and Sheffield) rose from 1,714,400 to 1,877,100[173]. During the same period, the GDP per head at current market prices rose from £11,941 to £21,661. Despite this growth, GDP per capita in Sheffield remains behind the national average. In 2017, the average GVA per capita for the UK £27,555 with annual growth in 'real' GVA of 1.9%. In the Sheffield City Region in 2017, GVA per capita was £18,652, though annual 'real' growth exceeded the UK average at 2.3%[174].

Employment in manufacturing continues to account for a small number of jobs in the Sheffield City Region, though this has risen recently both as a proportion and real terms. In 2016, 79,000 people in the Sheffield City Region were employed in manufacturing, 10.6% of all jobs. In 2018, this figure had risen to 92,000 and 12.2% of all jobs. For Great Britain as a whole, the percentage of people employed in manufacturing jobs during this period remained static at around 8.1%.

167. University of Sheffield. 2015 The UK's first Advanced Manufacturing Innovation District, https://www.sheffield.ac.uk/polopoly_fs/1.480177!/file/Innovation_District_Flyer.pdf (accessed on 24 May 2020).

168. Sheffield City Region. 2020 Global Innovation Corridor, https://scrinvest.com/global-innovation-corridor/ (accessed on 24 May 2020)

169. Lane, Laura *et al*. 2016 Sheffield City Story, http://eprints.lse.ac.uk/67849/1/casereport103.pdf (accessed on 24 May 2020).

170. Government Office for Yorkshire. 2008 European Structural Funds in South Yorkshire 2000-2008, https://ec.europa.eu/regional_policy/archive/country/commu/docoutils/o1_south_yorkshire.pdf (accessed on 24 May 2020).

171. *Ibid.*

172. *Ibid.*

173. Office for National Statistics. 2020 Labour Market Profile - Sheffield City Region, https://www.nomisweb.co.uk/reports/lmp/lep/1925185559/report.aspx?#ps (accessed on 24 May 2020).

174. Office for National Statistics. 2018 Regional economic activity by gross value added (balanced), UK: 1998 to 2017, https://www.ons.gov.uk/economy/grossvalueaddedgva/bulletins/regionalgrossvalueaddedbalanceduk/1998to2017 (accessed on 24 May 2020).

Less than twenty years since its creation, the AMP is now home to around 500 jobs in advanced manufacturing. Additionally, over 1000 apprentices have been trained on the sight by the AMRC[175]. The University of Sheffield employs 600 people on the AMP, 350 of whom are engineers and researchers[176]. The AMRC has now expanded beyond Sheffield, with locations in Derby and Broughton.

Since 1997, engineering at the University of Sheffield's has grown considerably. In 2019, it was first in the UK for income and investment in engineering research, attracting £124 million in public and private funding in 2018 – 18. In its submission to the 2014 Research Excellence Framework, the University highlighted the role of the AMRC in several of its impact case studies[177].

Looking forward

In less than twenty years Sheffield has established a cluster of activity in advanced manufacturing. While the number of jobs it has created has been relatively modest, there has been a recent increase in the number of manufacturing jobs in the Sheffield City Region in both relative and absolute terms.

The AMRC model does not require companies to be co-located to benefit from engagement, many companies integrate the learning into production facilities elsewhere. The choice of Boeing, McLaren and others to either open new facilities in Sheffield or to move to co-locate within the sites of the 'Advanced Manufacturing Innovation District' is significant. Further expansion will create greater opportunity and contribute toward the long-term viability of the cluster. The focus on innovation by Sheffield City Region Mayor Dan Jarvis MP also appears positive[178].

The development of the cluster has been led by local leadership from within academia and industry and benefitted from continued public sector support at regional, national and European level. The departure of the UK from the European Union could create challenges in terms of attracting and retaining staff as well as securing funding for future local development initiatives.

The aviation industry has been significantly affected by the coronavirus crisis[179] and so the knock-on effects of this are a cause of concern. The AMRC has contributed to the immediate national response to the crises.

175. Breach, Anthony. 2019 Parks and innovation: Lessons from Sheffield's Advanced Manufacturing Park, https://www.centreforcities.org/publication/parks-and-innovation/ (accessed on 24 May 2020).
176. Breach, Anthony. 2019 Parks and innovation: Lessons from Sheffield's Advanced Manufacturing Park, https://www.centreforcities.org/publication/parks-and-innovation/ (accessed on 24 May 2020).
177. Research Excellence Framework. 2014 REF 2014 Impact Case Studies, https://impact.ref.ac.uk/casestudies/Results.aspx?val=amrc (accessed on 24 May 2020).
178. Sheffield City Region. 2020 Priorities & Plans, https://sheffieldcityregion.org.uk/about-the-mayor/priorities-plans/ (accessed on 24 May 2020).
179. KPMG. 2020 COVID-19 and the global aviation industry, https://home.kpmg/xx/en/blogs/home/posts/2020/04/covid-19-and-the-global-aviation-industry.html (accessed on 24 May 2020).

Uppsala life sciences cluster

Introduction

The life science industry in the Stockholm-Uppsala region began to attract international headlines in the early 2000s. A special section in Nature lauded the 'world class scientific and business environment[180]'. The Economist described Uppsala alongside Cambridge in the UK as one of the most biotech-dense cities in the world[181].

The region is Sweden's largest life science cluster, home to just over half of the country's life science industry (over 20,000 employees), five universities and 650 life science companies[182]. Over the past decade, 15 to 20 new life science companies were formed in the region each year[183]. Stockholm-Uppsala usually ranks in top ten European biopharma clusters, and the sector was recognised as a national priority with the establishment of an Office for Life Sciences in 2019[184].

Despite the concentration of academic and industry activity, opinions differ on whether the cluster should be defined as an 'Uppsala cluster' or as part of the wider Stockholm-Uppsala region. We will refer to the Uppsala cluster, whilst recognising that activity spans different spatial dimensions: from informal networking and labour market dynamics at a regional level to business and academic relationships that span the globe[185]. Uppsala itself is just 70km from Stockholm and activities often bridge the two. With an international reputation as 'the city of methods' due to a traditional focus on the production of biotech research tools, Uppsala has a long history of industry and academia working closely together[186].

Development

The roots of the cluster can be traced to biotech research conducted at Uppsala University during the 1920s and 1930s. However, larger-scale industrial activity was sparked by the Swedish pharmaceutical company Pharmacia relocating from Stockholm to Uppsala in the 1950s. A major reason for the move was a history of collaboration between Pharmacia and a research unit at Uppsala University built on the contribution of two Swedish Nobel Laureates in chemistry: Theodor Svedberg and Arne Tiselius[187].

In 1995 Pharmacia, then one of the largest pharmaceutical companies in Europe, merged with the US company Upjohn, leading to protracted restructuring and relocating – including the move of some R&D and marketing activities to the US[188]. Product and research focus shifted to match those of the new owners.

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180. Waluszewski, Alexandra. 2004. A competing or co-operating cluster or seven decades of combinatory resources? What's behind a prospering biotech valley?, https://ideas.repec.org/a/eee/scaman/v20yi1-2p125-150.html (accessed on 12 May 2020).
181. Waxell, Anders. 2016 Writing up the region: anchor firm dismantling and the construction of a perceived regional advantage in Swedish news media, https://www.tandfonline.com/doi/abs/10.1080/09654313.2015.1128885?journalCode=ceps20 (accessed on 12 May 2020).
182. Stockholm Science City Foundation. 2018 Facts about Stockholm-Uppsala life science cluster, https://ssci.se/en/news/facts-about-stockholm-uppsala-life-science-cluster (accessed on 12 May 2020).
183. Invest Stockholm. 2020 Life Science in Stockholm, https://www.investstockholm.com/investment_opportunities/lifescience/ (accessed on 12 May 2020).
184. Biospace. 2019 Ranking the Top 10 Biotech Clusters in Europe, https://www.biospace.com/article/ranking-the-top-10-biotech-clusters-in-europe (accessed on 12 May 2020).
185. Waxell, Anders *et al*. 2007 What is global and what is local in knowledge-generating interaction? The case of the biotech cluster in Uppsala, Sweden. Entrepreneurship and Regional Development, https://www.tandfonline.com/doi/abs/10.1080/08985620601061184 (accessed on 12 May 2020).
186. Teigland, Robin *et al*. 2007. Seeing eye-to-eye: how do public and private sector views of a biotech cluster and its cluster initiative differ?, https://www.tandfonline.com/doi/abs/10.1080/09654310701214291 (accessed on 12 May 2020)
187. *Op. cit.* note 185.
188. *Op cit.* note 181.

The company adopted an American business culture: "competence originated at the top of the company and filtered down through the organisation" – at odds with the Scandinavian culture of delegated decision-making[189]. Around 200 research and managerial positions were moved out of Uppsala; the move was initially seen as striking a huge blow to the region[190].

As Pharmacia withdrew, a new narrative began to emerge. The vacuum left by company's withdrawal led to a frenzy of entrepreneurial start-ups and innovative ideas[191]. Soon after, there was an influx of new capital to the cluster, further boosting the growth of life science research and enterprise in the region.

The capital was not sourced locally, but from foreign investors and venture capital firms in the greater Stockholm region attracted by the technologies developed at Pharmacia[192]. In a detailed deconstruction of the popular narrative, Alexandra Waluszewski has shown how the emergence of the Uppsala cluster is not simply the result of (or the aftermath of) a single critical event, but the interaction of 'stable and healthy' industrial and academic units over at least 70 years[193]. She concludes that, "a closer look at the 'new' life science/biotech companies' population in the Uppsala region reveals that most of them have a long history. The majority have their resource roots in projects initiated long before the restructuring of Pharmacia. Many of them have existed for decades, sometimes as visible companies, sometimes hidden as projects within different parts of the universities or companies. The small company Medical Products Octagon is an illustrative example. The company was established in 1971 but existed as a project in the early 1960s. As one of the initiators, Professor Uno Erikson, explains: "We were many researchers with our daily work at the University hospital, within such disciplines as anaesthesia, physiology, radiology, cardiology, etc., and continually experienced technological problems connected to available equipment and material. It was this displeasure, and particularly all the negative effects we saw on the patients, that triggered us to use our medical knowledge for the development of new technological solutions. However, for decades we were forced to handle this work—development of new solutions, patents and licenses—in secrecy. For a professor at Uppsala University running a business was regarded as very suspect"[194].

As such, several key organisations including Uppsala University and its research hospital, the University of Agriculture, the biotech instrument producer GE Healthcare, and Phadia (blood test systems) have acted as 'anchor' institutions, and have had an important role in the formation of many new companies[195]. This includes through spin-outs, knowledge generation and dissemination, and access to research labs, but also customer and supplier connections, sharing of prototyping expertise and production facilities, and business support and advice. Growth has also been stimulated by governmental agencies located in Uppsala, including the National Veterinary Institute and the Medical Products Agency[196].

189. *Op cit.* note 180.
190. *Op. cit.* note 185.
191. *Op cit.* note 180.
192. *Ibid.*
193. *Op cit.* note 180.
194. *Ibid.*
195. Waxell, Anders. 2009 Guilty by association: a cross-industrial approach to sourcing complementary knowledge in the Uppsala biotechnology cluster, https://www.tandfonline.com/doi/abs/10.1080/09654310903230533 (accessed on 12 May 2020).
196. *Op. cit.* note 185.

However, this does not diminish the importance of Pharmacia in shaping Uppsala's life sciences cluster. Both GE Healthcare and Phadia have their roots in Pharmacia's restructuring (and interactions with Uppsala University's Department of Biochemistry); Pharmacia itself is now part of Pfizer and retains a presence in the region. Indeed, seven of the ten largest companies have some form of Pharmacia heritage[197]. A second legacy is the significant local knowledge pool in several biotech areas; the development of specialised methods, instruments, and research tools is considered the traditional core of the cluster and underpins Uppsala's reputation as a 'city of methods', whilst differentiating it from national competitors[198].

Uppsala BIO was created in 2003 by local representatives from government, industry, and academia[199]. Cluster initiatives raise the awareness of the work within a cluster, provide platforms for dialogue and decision-making (especially around the business environment), and perform the important intermediary activities of brokerage, facilitation and promotion[200]. A study of Swedish cluster initiatives found successful bodies struck a balance between being relevant for members and being open to new perspectives; Uppsala BIO offers training and networking for Uppsala's life science industry, but also 'open house' networking and knowledge-exchange activities[201]. Promotion and marketing have been an important thread in Uppsala's life sciences cluster development, and Uppsala BIO is part of this continued effort.

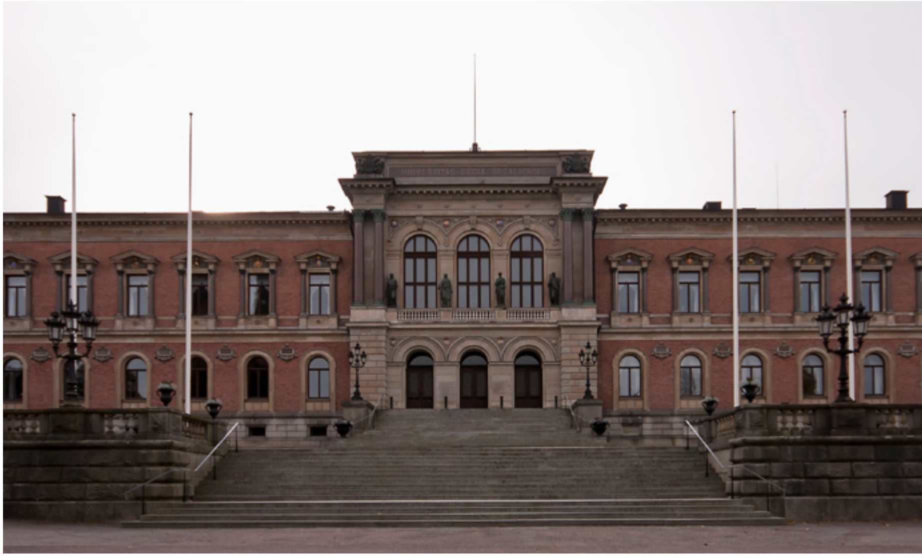

Image
Uppsala University.
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Outcomes

Swedish academics have found that the cluster played an important role in national economic restructuring from the 1970s, and was the engine of national life science growth[202]. Specifically, academic and industry collaboration led to the discovery of Sephadex, a gel filtration medium, in 1959, and immunoglobulin E, used to diagnose and treat allergies, in 1967. And this collaboration more generally led to the growth of Pharmacia as one of Europe's largest pharmaceutical companies, an important actor in the economic growth of the region, and convenor of talented researchers and managers. As such, Pharmacia has been described as 'the third University' in Uppsala (together with Uppsala University and the Swedish Agricultural University[203]).

197. *Op. cit.* note 182.

198. *Op. cit.* note 185.

199. Laur, Inessa *et al*. 2012 Catching Regional Development Dreams: A Study of Cluster Initiatives as Intermediaries, https://www.tandfonline.com/doi/abs/10.1080/09654313.2012.725161 (accessed on 12 May 2020).

200. Laur, Inessa *et al*. 2012 Catching Regional Development Dreams: A Study of Cluster Initiatives as Intermediaries, https://www.tandfonline.com/doi/abs/10.1080/09654313.2012.725161 (accessed on 12 May 2020).

201. Laur, Inessa *et al*. 2012 Catching Regional Development Dreams: A Study of Cluster Initiatives as Intermediaries, https://www.tandfonline.com/doi/abs/10.1080/09654313.2012.725161 (accessed on 12 May 2020).

202. Moodysson, Jerker, *et al*. 2008 Clusters in Time and Space: Understanding the Growth and Transformation of Life Science in Scania, https://ideas.repec.org/p/hhs/lucirc/2008_004.html (accessed on 12 May 2020)

203. *Op. cit.* note 185.

The result today is a mature ecosystem. There are several markers of this. First, the growth of specialised services firms in and around the cluster, including in business development, patenting and legal advice, recruitment and marketing[204]. Specialised consultancy firms also help to fill gaps within biotechnology start-ups[205]. A second marker is the growth of informal contact between industry and academia, built overtime on the foundations of formal relationships. The result of this physical and social proximity is the rapid circulation and spillover of knowledge and ideas within the cluster, well-developed social networks, and easy access to global contacts and channels. Individuals can easily switch firms and move from industry to academia and vice versa, transferring knowledge and further strengthening relationships[206].

Despite strong collaboration and professional mobility within the cluster, there are differences between public and private sector organisations, and – as one might expect – differing views on the priorities and strengths of the cluster. Their interactions differ too, perhaps to the overall benefit of the cluster. Public sector organisations tend to interact more with biotech companies at a national level than their private sector counterparts, whereas private sector companies interact more often with biotech companies at an international level. Both, however, rank the cluster's work in developing methods and tools for discovery as the greatest strength, followed by diagnostic work[207].

Looking forward

The Uppsala cluster is closely intertwined with inward investment efforts from Invest Stockholm and other bodies, in targeted areas such as applying artificial intelligence and machine learning to life sciences, and health tech[208]. This builds on Stockholm-Uppsala Life Science (SULS), a joint effort between Uppsala BIO and Stockholm city to actively market the region's life science outside of Sweden which began in 2007[209].

Previous analyses have found that the venture capital sector in Uppsala is heavily underdeveloped in terms of the number of local actors[210]. However, this is perhaps symptomatic of the country as a whole, rather than an issue of local provision: an earlier study found that 84% of venture capital invested in Swedish drug discovery firms was in the Stockholm-Uppsala region[211].

Finally, and despite high-quality R&D, Sweden faces challenges that may affect the cluster. These include the level of patenting, and small companies facing a choice between licensing products to 'big pharma' or being acquired. This has led to fears of stunted company growth, inhibiting the development of a thriving, home-grown sector[212].

204. *Op. cit.* note 186.
205. *Op. cit.* note 195.
206. *Op. cit.* note 185.
207. *Op. cit.* note 186.
208. Uppsala Bio. 2017 Health Tech: Business Opportunities in Stockholm-Uppsala, https://www.uppsalabio.com/wp-content/uploads/2017/05/health_tech_2017.pdf (accessed on 12 May 2020).
209. Uppsala Bio. 2017 Life science in the Stockholm-Uppsala region, https://www.uppsalabio.com/facts-figures/stockholm-uppsala-region/ (accessed on 12 May 2020).
210. *Op. cit.* note 195.
211. Valentin, Finn *et al*. 2008. How venture capital shapes emerging bio-clusters—a cross-country comparison, https://www.tandfonline.com/doi/abs/10.1080/09654310801920631?journalCode=ceps20 (accessed on 12 May 2020).
212. ScienceI Business. 2015 The leading life sciences clusters in Europe, https://sciencebusiness.net/report/leading-life-sciences-clusters-europe (accessed on 12 May 2020).

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