Success Factors for High-Technology Entrepreneurial Ecosystems: Leveraging University Knowledge Assets within Science and Technology Parks

by

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Abstract

High-tech entrepreneurship ecosystems depend heavily on the growth dynamics and performance of Science and Technology Parks (STPs), where collaborations among New Technology-Based Firms (NTBFs), universities, and large firms play a pivotal role as conceptualized in the Triple Helix model. Through analysing Swedish STPs, such as Umeå and Skövde, alongside UK pharmaceutical-focused STPs, this study demonstrates that younger STPs gain resilience and improved decision-making through partnerships with large firms, while mature STPs derive more benefits from clustering similarly specialized firms to promote knowledge spillovers, irrespective of university proximity. Geographic Information Systems (GIS) analysis reveals that STPs with overlapping specializations maintain distances exceeding 33 km, while those with distinct focuses are often situated closer, sometimes as little as 12 km apart, underscoring the importance of spatial arrangements in enhancing STP performance.

The research builds upon prior findings that STPs achieve optimal decision-making with input from two large firms, as additional firms introduce increased transaction costs. The analysis of SKÖVDE Science Park, which includes two large firms, reveals a notably high on-cluster employment gradient of 56.85, while UMEÅ Science Park, lacking large-firm partnerships, shows a much lower gradient of 12.00, thus validating the proposed model's hypothesis on the critical role of large firms in fostering robust STP performance.

In examining Technology Transfer Office (TTO) structures, this research employs Monte Carlo modelling to reveal that non-hierarchical, hybrid management models enhance innovation transfer efficiency over traditional hierarchical structures. These findings challenge the universal applicability of established frameworks like the Triple Helix and entrepreneurial university models, suggesting these concepts may require contextual adaptation to support sustainability within high-tech ecosystems effectively.

A longitudinal analysis (2009–2022) of state-funded research identifies high-performing UK universities, where firms linked to successful university grants outperformed control groups by up to 400%. Firms associated with Arts and Humanities Research Council (AHRC) and Innovate UK grants showed 20% and 18% performance gains, respectively. Spatial analysis revealed no significant clustering around universities, with partner firms often located over 100 km from lead institutions. These findings enhance understanding of STP development, regional economic policy, and innovation ecosystem sustainability, providing a refined framework for high-tech entrepreneurship studies within STPs.

Publications

Journal Papers:

Mondal, C. and Mellor, R.B. (2021) 'Analyses of small and medium-sized science and Technology Parks show that longer-term growth may depend upon attracting larger partners', *International Journal of Management and Enterprise Development*, 20(3), p. 311. doi:10.1504/ijmed.2021.118416.

Mondal, C., Adilkhan Kussainov and Mellor, R.B. (2021). Modelling the number of client firms needed to support a new Science Park and the spacing between new parks and existing parks with similar themes. *International journal of knowledge-based development*, 12(2), pp.141–141. doi.org/10.1504/ijkbd.2021.121716.

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Mondal, C. and Mellor, R.B. (2021) 'Towards a unified model of Science Park.' In: 22nd European Conference on Knowledge Management (ECKM 2021), 2nd – 3rd September 2021, Coventry, UK.

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List of Abbreviations:

AHRC – Arts and Humanities Research Council

ANOVA - Analysis of Variance

AOI - Areas of Innovation

CI - Cluster Initiative

COVID – Coronavirus Disease

CRN - Companies House Registered Number

GDP – Gross Domestic Product

GIS - Geographic Information Systems

Gov. – Government

GtR - Gateway to Research

HEI - Higher Education Institution

IASP - International Association of Science Parks and Areas of Innovations

IPO - Initial Public Offering

IPR - Intellectual Property Rights

MCDM - Multi-Criteria Decision-Making

MU - Monetary Unit

NOE – Number of Employees

NOF – Number of Firms

NTBF – New Technology-Based Firm

R&D – Research and Development

SEM - Structural Equation Modelling

SIC - Standard Industrial Classification

STP – Science and Technology Parks

TPV - Total Patent Value

TTO – Technology Transfer Office

UK – United Kingdom

UoA - Unit of Assessment

1 Introduction

1.1 Background and Key Challenges

The technological entrepreneurial ecosystem is of paramount importance to the economic well-being of a nation (Porter, 1990). One noteworthy characteristic of this system is the presence of "technological districts", which include Science Technology Parks (STPs); however, achieving high levels of competitiveness and growth is not a straightforward task, and only a few are able to succeed (Wadhwa, 2013; Kelly and Firestone, 2016).

In recent years, there has been a trend towards an innovation-driven global economy in which clusters of innovative firms are thought of as important for sustained regional growth. These clusters, also known as innovation ecosystems, comprise dynamic knowledge-based entrepreneurial activities that form networks to support innovation (Suominen et al., 2019). A significant number of studies have been conducted to define the concept of innovation ecosystems and establish a framework for understanding their operations (Chang et al., 2010). Alongside heightened competition and globalisation, where distance, transportation costs, and natural resources no longer significantly impact regional development (Porter and Porter, 1998), national and regional governments are increasingly seeking to generate value by leveraging specific knowledge ecosystems. These ecosystems, which include business incubators and venture capital, are intended to connect a reputable scientific base with advanced knowledge of business and finance, thereby fostering business clusters.

Unfortunately, recent studies indicate that a significant proportion of business clusters have experienced failure. For instance, a recent World Bank report estimated a 26% failure rate for technology hubs in Africa (Kelly and Firestone, 2016). Furthermore, Wadhwa (2013) posited that "*Sadly, the magic never happened anywhere. Hundreds of regions all over the world collectively spent tens of billions of dollars trying to build their versions of Silicon Valley. I don't know of a single success*". Similarly, in the UK, the success rate in Wales was 40% (BBC, 2010; Pugh et al., 2018), resulting in a substantial cost to UK taxpayers of hundreds of millions. This underscores the need to establish a set of indicators to measure the success of business clusters and a mechanism for evaluating their performance. Alongside the necessity to determine whether they are progressing towards becoming a well-liked and prosperous business cluster or identifying the obstacles and devising strategies to overcome them, it is essential to explore the path they are currently on.

The challenge of fostering successful technological districts, such as Science and Technology Parks (STPs), is underscored by the high failure rates observed globally. Despite significant investments, many regions have struggled to replicate the success of renowned innovation clusters like Silicon Valley. STPs are designed to foster innovation and contribute to regional development by creating a collaborative environment. However, the effectiveness of STPs is currently under scrutiny due to several emerging challenges.

The critical role of STPs in fostering innovation and regional development is well-documented, yet their success rates and operational dynamics reveal several complexities that necessitate a deeper examination. The following points outline the justification for investigating the current challenges and effectiveness of STPs:

1.1.1 Challenges of the Triple-Helix Model in STPs:

STPs play a pivotal role in fostering innovation by offering collaborative environments for start-ups. The "Triple-Helix" model, which involves the collaboration between universities, businesses, and government entities, is a fundamental aspect of STPs (Leydesdorff and Etzkowitz, 1996). However, recent reviews have raised concerns about the effectiveness of the "Triple-Helix" model, highlighting the challenges associated with the narrow asset specificity required for successful co-operation between businesses and universities (Johnston and Huggins, 2018; Johnston, 2019, 2020; Ng et al., 2019; Lecluyse et al., 2019; Hobbs et al., 2017). University research laboratories, which were once instrumental in incubating start-ups, are now facing challenges in securing research contracts from established businesses. (Perkmann et al., 2013; Winters and Stam, 2007).

1.1.2 Regional Factors and the Feasibility of STPs:

The efficacy of STPs is greatly impacted by regional factors, which necessitates a more profound comprehension of these elements (Łobacz, 2018; Löfsten and Lindelöf, 2002). Despite receiving state support, only a small fraction of STPs attain long-term success, thereby raising questions regarding their feasibility and strategic orientation of regional planning (Cadorin et al., 2019; Leitão et al., 2022; Wadhwa, 2013; Kelly and Firestone, 2016; Pugh et al., 2018).

1.1.3 Organizational Architecture and STP Performance with Advanced Methodologies:

Al-Kfairy and Mellor (2020) have brought into question the assumed universal benefits of all innovations and emphasised how organisational architecture influences corporate performance within STPs. This is based on ideas presented by Will et al. (2019) that adopting poor-fit innovations will be costly.

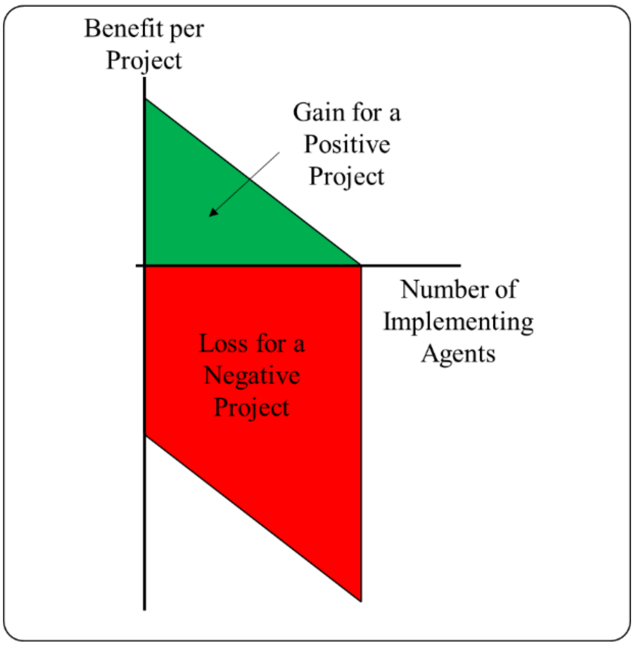


Figure 1.1: Gains and losses in the case of innovations with spillover effects (green triangle: myopia in the case of a good innovation; red quadrilateral: myopia in the case of a bad innovation) (Will et al., 2019)

Employing advanced methodologies such as Structural Equation Modelling (SEM), Monte Carlo techniques, and Geographic Information Systems (GIS) aims to investigate and address the issues in STP performance (Al-Kfairy et al., 2020; Kussainov et al., 2020; Mellor, 2018).

1.1.4 Impact of Larger Firm Managers on STP Decision-Making:

The challenges also lie in making effective decisions within STPs. Experienced managers from larger firms may enhance the strategic direction of STPs (Albahari et al., 2018; Wegner and Mozzato, 2019). The involvement of larger firms in STPs can significantly impact their success and optimal results are often observed when two such firms are present (Mondal and Mellor, 2021).

1.1.5 STP Success and Industry-University Collaboration Challenges:

Achieving success in Science and Technology Parks (STPs) is a considerable challenge, with studies showing that only about 20% of STPs achieve success (Wadhwa, 2013; Kelly and Firestone, 2016; Pugh et al., 2018). This challenge is further compounded by the need for high asset specificity in successful industry-university collaborations, as emphasised by recent research (Hobbs et al., 2017; Johnston and Huggins, 2018; Johnston, 2019; Ng et al., 2019; Lecluyse et al., 2019; Johnston, 2020).

1.2 Research Aims and Objectives

1.2.1 To evaluate the development and sustainability of on-cluster vs off-cluster firms in STPs:

Science and Technology Parks (STPs) play a significant role in fostering the growth of small innovative start-ups, which, in turn, contributes to regional development (Cadorin et al., 2019). According to Al-Kfairy and Mellor (2020), the decision-making process for admitting new innovative firms to participate in STPs is initially informal, with minimal consequences for mistakes and reasonable management costs. However, as the STP expands, poor decisions can have detrimental effects, leading to market failure or the need for reorientation toward other services, such as hosting general businesses or incubator services (Albahari et al., 2018). To prevent such outcomes, it is essential for the central unit of the STP entity, often referred to as the Cluster Initiative or CI, to make informed decisions. This can be achieved by involving experienced managers with relevant knowledge from larger firms (Wegner and Mozzato, 2019). While drawing upon resources from two larger firms can improve decision-making, it also incurs transaction costs (Al-Kfairy and Mellor, 2020). Therefore, it is most beneficial to strike a balance between better decision-making and associated costs. Comprehending the intricacies of STPs' performance is essential for maximising their capacity to promote innovation and economic expansion.

This study aims to evaluate the contrasting development of on-cluster firms in STPs and the off-cluster firms in the municipalities but outside the STPs. The objective is to gain insight into the factors that contribute to the long-term growth and sustainability of science and technology parks, with a particular focus on the role played by larger partners in enhancing decision-making and overall performance. To achieve this, the research will address the following questions:

a) How do the growth patterns of small and medium-sized enterprises (SMEs) located within science and technology park (STP) clusters differ from those situated outside the clusters in municipalities, specifically comparing young parks like Umeå with mature parks like Skövde?
b) In what ways do the employment contributions of on-cluster SMEs compare with those of off-cluster SMEs in both young and mature science and technology parks, and what factors influence these differences?
c) How does the presence of larger partner organisations within science and technology parks influence the decision-making processes and contribute to the long-term growth and sustainability of these parks?

1.2.2 To optimize collaboration and foster innovation within STPs:

Science and Technology Parks (STPs) are areas where new technology-based firms (NTBFs) and small and medium enterprises (SMEs) clusters foster innovation, often linked to nearby universities for knowledge access (Lecluyse et al., 2019). The recently developed COVID-19 vaccines by using techniques developed from either Oxford University or NTBF BioNTech prompted us to explore the potential for collaboration between universities, innovative firms, and STPs in the pharmaceutical sector to bring new products to the market. This conduct is at the core of the so-called "Triple-Helix" model, as described by Etzkowitz and Ledersdorff (1995). However, critical quantitative metrics related to establishing new STPs appear to be absent from the "Triple-Helix" model (Etzkowitz and Ledersdorff, 2000).

This study aims to formulate a model for assessing the optimal number of specialised firms necessary in a particular area to facilitate the establishment of a new and similar specialised STP. Moreover, this approach seeks to provide an estimate of the proximity that a new and specialised STP can maintain with established STPs possessing a similar specialisation when compared with STPs having distinct specialisations. This research endeavours to explore the relationship between the typical distance between Science and Technology Parks (STPs) and prominent universities, as well as the efficacy of on-campus and off-campus STPs in drawing specialised businesses that are attracted by high-ranking universities. To explore these aims, the study will investigate the following research questions:

a) What is the requisite number of client firms necessary to ensure the sustainability of a new science park, with a particular focus on those specialising in the pharmaceutical sector in the United Kingdom, and how do these parks spatially distribute and form clusters in relation to top-ranking universities renowned for pharmaceutical research?
b) Are on-campus science parks more successful in attracting specialised pharmaceutical firms than their off-campus counterparts, and what is the optimal radius for fostering such specialisation to ensure long-term sustainability?

1.2.3 To establish a sustainable tech entrepreneurship ecosystem:

Lim et al. (2022) found that investments in public infrastructure within science and technology parks (STPs) led to sustainable improvements in environmental quality and business ecosystems. However, there are paradoxes associated with STPs. Their development aims to foster a "knowledge economy" and is particularly attractive to economically disadvantaged regions due to potential economic growth (Cadorin et al.,2019; Leitão et al., 2022). Despite expectations of significant returns and state support, only about 20% of STPs achieve long-term success (Wadhwa, 2013; Kelly and Firestone, 2016; Pugh et al., 2018). Sustainability in both regional and entrepreneurial contexts is of paramount importance, especially during economic downturns, when the temptation to establish additional STPs may be heightened. However, this approach may be misguided and result in the creation of non-viable STPs that squander resources and potentially undermine the success of neighbouring STPs that are only marginally viable.

This study investigates the organic growth of young technology start-up parks using big data, econometric analyses, panel data, and computer simulations, with the aim of establishing a sustainable ecosystem for high-value tech entrepreneurship. The research draws upon findings from industrialised countries, such as the UK and Sweden, which may be applicable to other regions and emerging economies. The insights gained from this research will be of great value to those involved in regional development, as well as technology entrepreneurs looking to establish a science and technology park and central teams focused on the management and sustainable growth of new parks. To investigate this, the study will explore the following research question:

a) Which key factors contribute to the development of a sustainable ecosystem for high-value tech entrepreneurship within science and technology parks? and,
b) How can these factors be optimised using insights gained from big data analytics, econometric models, and computer simulations?

1.2.4 To investigate the most effective approaches for facilitating the transfer of technology within entrepreneurial environments:

The innovation pipeline process necessitates an ambidextrous approach that integrates research, management, innovation, and entrepreneurship (Audretsch and Guerrero, 2023) to facilitate the transfer of innovation from its source, such as university research, to an external recipient. The process requires a high-level decision by the university hierarchy to deem the progress towards commercialisation worthy of investment, which covers transaction costs, including staff time and patenting. It is important to note that the costs of failed innovation typically exceed the benefits of successful innovation (Will et al., 2019). As a result, a traditional, non-entrepreneurial university may exhibit risk-averse behaviour, such as waiving rights and allowing inventors and researchers to independently advance their innovations. This behaviour is often successful in highly regulated environments (Will et al., 2017). However, from a user perspective, Hegde and Tumlinson (2020) developed a probabilistic model as a nonlinear

Bayesian optimisation problem, highlighting that while university academics possess high credentials, their entrepreneurial intent and experience are often limited. This may present challenges for research employees transitioning to entrepreneurship regarding marketing innovations.

Conversely, an entrepreneurial university might invest in innovations and necessary infrastructure such as decision-making processes, investor relations, and the costs of maintaining a Technology Transfer Office (TTO), where the expected returns exceed these investments (Harmon et al., 1997). This underscores TTO's role as a bridge between the knowledge source and recipient, as highlighted by Panetti and Parmentola (2020). Once the innovation exits the university and becomes part of an independent entity - whether spun out from the university or entirely separate, as described by Günsel (2015) - it may integrate into a high-tech entrepreneurship ecosystem, such as a Science and Technology Park (Germain et al., 2022; Mondal et al., 2023).

This study also investigates the optimal strategies for transitioning from purely research-oriented endeavours to a high-technology entrepreneurship ecosystem, specifically by examining the effective functioning of the innovation pipeline that spans the period from leaving the research laboratory to integrating with recipients. This study aims to delve into the organisational structure of a Technology Transfer Office (TTO), with a particular focus on successfully transferring university research-developed technologies to external recipients. To further explore this topic, the following questions are raised:

a) How do hierarchical decision-making models within universities impact the initial trajectory of innovation from research to commercialisation and what are the performance differences between these models and ambidextrous cooperative team structures within Technology Transfer Offices (TTOs)?

1.2.5 To investigate the innovation pathways and economic outcomes of knowledge producers:

Many researchers often discuss the concept of "knowledge spillovers," in which innovation producers share their knowledge with innovation users, who subsequently aim to apply this knowledge for commercial purposes. However, the pathway through which innovation takes place is not well defined in this context. For instance, Roper et al. (2022) pointed out that firms seeking innovation may have different approaches to acquiring knowledge than those seeking to benefit from imitation. This underscores the significance of the academic knowledge source, and should consider the recipient's knowledge-acquiring status (as highlighted by Zieba, 2021) and the level of novelty involved (as noted by Seidle, 2024). Although Mondal et al. (2024) used SEM to investigate the optimal management structure for university technology transfer, they found that, in theory, a management-light team structure is most effective. However, this has not yet been proven using empirical evidence.

This study aims to identify successful knowledge producers who are able to transfer innovations and are able to use this as a starting point to investigate their innovation pathways. To achieve this, we conduct a longitudinal analysis of the financial performance of companies included in state-funded projects, which will allow us to identify under and over-performing universities. To further explore this topic, we examined data from the UK's 'Gateway to Research' (GtR) database to identify firms that have received funding from the UK research councils and focus on comparing the economic outcomes of companies involved in funded projects. The research aims to address the following questions:

a) How does the annual financial performance of firms involved in state-funded projects compare with that of control groups and what are the differential impacts of these projects on firm performance?
b) How do variations in Standard Industrial Classification (SIC) codes and geographical locations affect the financial performance of firms participating in successful funding projects? Additionally, which universities are associated with firms that exhibit superior financial outcomes, and what factors account for these disparities?

Figure 1.2: Study/Analysis Flow by Chapters

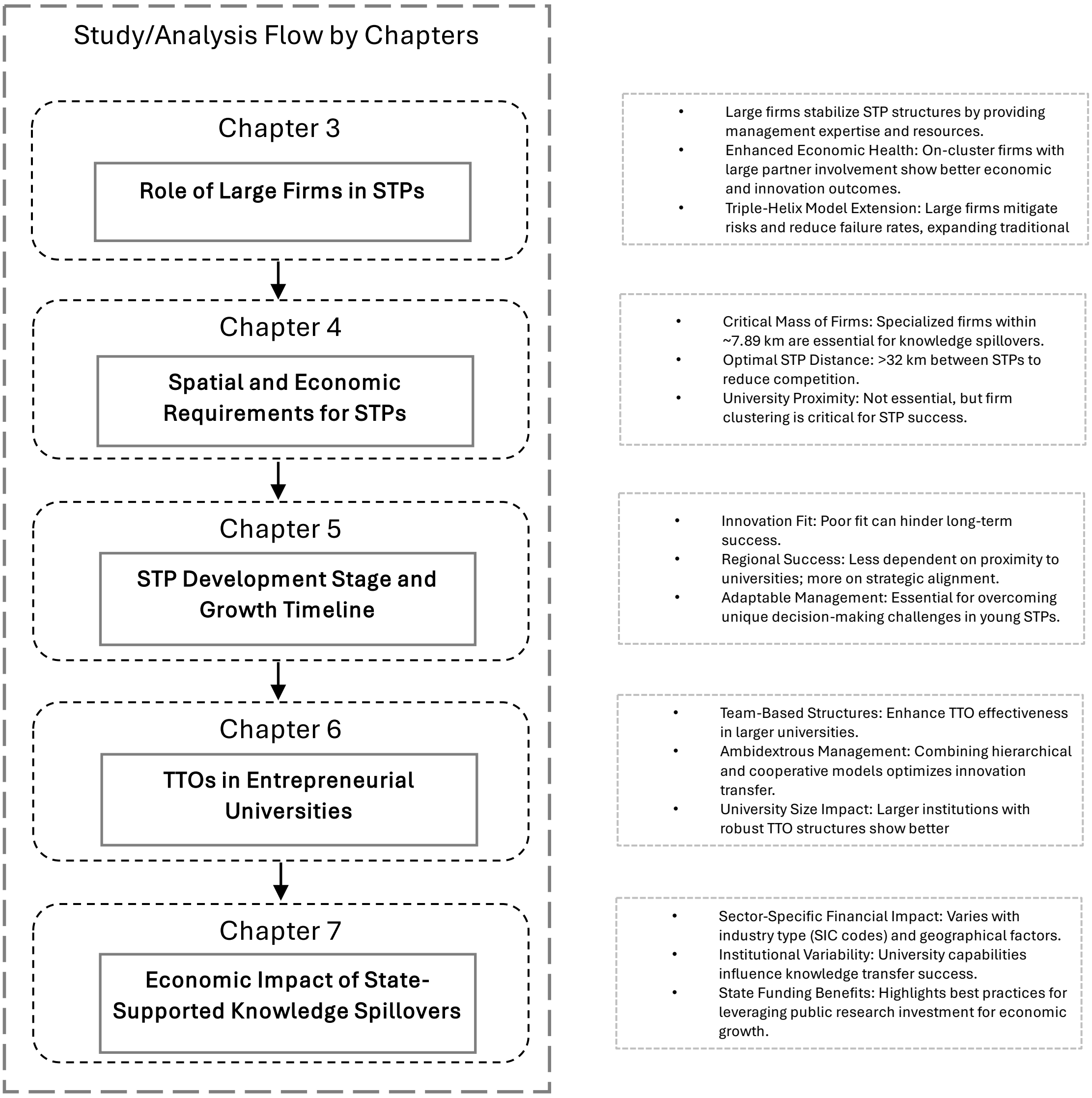
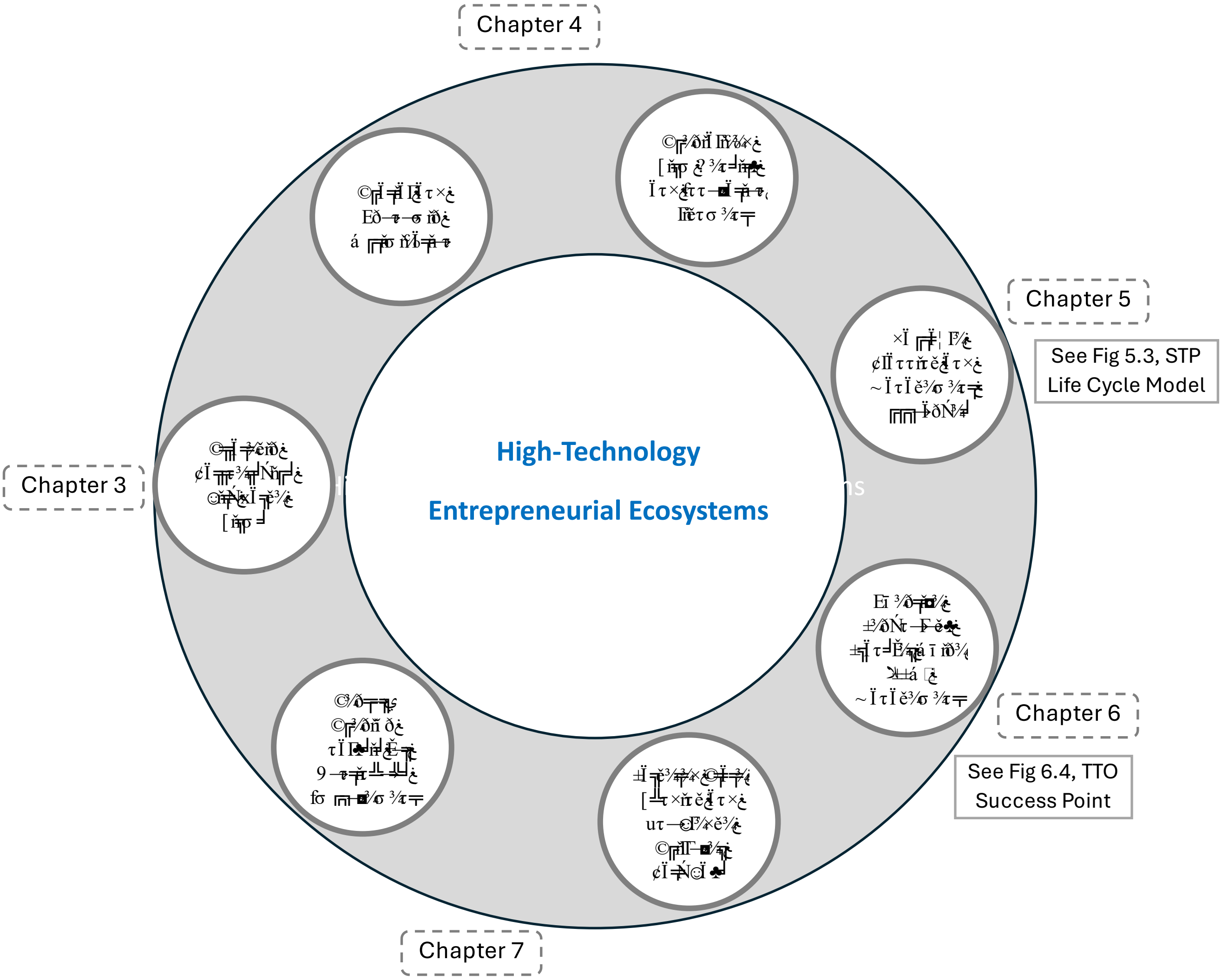


Figure 1.3: Model of Success Factors for Science and Technology Parks Integrated into High-Technology Entrepreneurial Ecosystems



1.3 Structure of the Document

Table 1.1 shows how the thesis is organised, describing each of the chapters and its objectives and content.

Table 1.1 Structure of the Document

Chapter Name	Description
Chapter 2	This chapter provides a comprehensive analysis of Science and Technology Parks (STPs), covering their historical evolution, spatial and

	organizational structures, and roles within innovation ecosystems. It examines the impact of collaborations between NTBFs, universities, and large firms on STP performance and the role of Technology Transfer Offices (TTOs) in supporting the 'triple-helix' model. The chapter also addresses the influence of government policies and international perspectives.
Chapter 3	Examines the growth of on-cluster and off-cluster SMEs and municipal STPs in Umeå and Skövde, analysing panel data to explore the economic health of firms in smaller STPs with either none or two larger firms in residence.
Chapter 4	A comprehensive analysis of UK Science and Technology Parks (STPs) specialising in pharmaceuticals, compared to leading pharmaceutical research universities and firms listed under the relevant Standard Industry Classification (SIC) codes at Companies House. Using a data-driven approach to address technology transfer challenges, COVID-19 related issues, research impact metrics, and the implementation of start-up STPs in regional development and government policymaking.
Chapter 5	Analyses of the expansion of Science and Technology Parks (STPs) using data-driven strategies and insights gathered from countries such as Sweden and the United Kingdom. The findings of this study are of significant importance to those involved in regional development, technology entrepreneurs, and the management of STPs who are focused on achieving sustainable growth.
Chapter 6	Examine the process of transferring innovations from university research to external recipients, with a particular emphasis on the role of Technology Transfer Offices (TTOs). This report aims to identify the most effective strategies for transitioning from basic research to a thriving ecosystem of high-tech entrepreneurship.
Chapter 7	This chapter examines the financial performance of companies involved in state-funded initiatives by Innovate UK and the Arts and Humanities Research Council (AHRC) from 2009 to 2012. Utilising the UK 'Gateway to Research' database and Companies House data, the study tracks these companies' financial trajectories from 2012 to 2022. The analysis

	identifies high and low-performing universities and assesses the success of technology transfer from these institutions.
Chapter 8	Thesis Conclusion: This chapter summarises the key findings on Science and Technology Parks (STPs), emphasising their role in innovation and economic growth through collaboration with larger firms. It discusses the theoretical and practical implications and study limitations and suggests future research directions.
Chapter 9	Shows the list of references
Appendix	Comprehensive list of Standard Industrial Classification (SIC) codes and their descriptions for companies involved in AHRC and Innovate UK projects.
Glossary	List of definitions of terms.

2 Literature Review

2.1 Introduction

In the contemporary landscape of technological advancement and economic globalisation, Science Technology Parks (STPs) have emerged as pivotal institutions that drive innovation, economic growth, and societal progress. These dynamic ecosystems serve as fertile grounds where the seeds of research, collaboration, and entrepreneurship are sown, cultivated, and harvested into tangible solutions that address pressing societal challenges and propel industrial competitiveness. Embarking on a journey through the annals of STP literature, this comprehensive review aims to illuminate the multifaceted dimensions of STPs, encompassing their historical evolution, spatial dynamics, organisational structures, success criteria, government perspectives, challenges, and unexplored areas with respect to the success criteria of STPs.

2.1.1 The evolution of STPs

Science and technology parks (STPs) were established in the mid-20th century as research parks to encourage collaboration between academia and industry (Phan et al., 2005). Initially, their purpose was to facilitate interdisciplinary collaboration, knowledge sharing, and technology commercialisation, but they have since expanded their scope to include providing infrastructure, driving regional economic growth, creating jobs, and contributing to societal progress (Bayat et al., 2022). Today, STPs are seen as symbols of innovation excellence and are essential for nurturing knowledge-intensive industries that drive economic growth and global competitiveness (Bayat et al., 2022).

STPs now encompass various advanced technology hubs, such as science parks, innovation centres, and technology incubation centres (Akgün and Güner, 2022). These hubs function as catalysts for innovation, creativity, and ecosystem growth (Germain et al., 2022). By offering an incubator environment, STPs facilitate the transformation of academic research into commercial products (Löfsten et al., 2020) and provide geographic and organisational advantages for effective knowledge exchange with local Higher Education Institutions (HEIs) (Fukugawa, 2006).

2.1.2 Spatial dynamics and collaboration

The arrangement and proximity of stakeholders within science and technology parks considerably affects collaboration dynamics, the flow of knowledge, and the formation of innovation clusters (Tataj et al., 2022). By bringing together entities, such as academic institutions, research organisations, technology-based start-ups, and multinational corporations, science and technology parks foster synergistic relationships that transform ideas into marketable products and services (Tataj et al., 2022). The success of science and technology parks is significantly influenced by geographic clustering and collaboration dynamics, which are driven by knowledge spillover, technology transfer, and entrepreneurial networking, all of which are essential for effective resource allocation, talent retention, and sustainable regional development (Balle et al., 2019).

Research has shown that science and technology parks significantly impact innovation by facilitating knowledge spillovers through firm networking (Al-Kfairy et al., 2020). Studies highlight the importance of stakeholder participation and problem definition in collaborative systems for comprehensive decision-making (Curşeu and Schruijer, 2020). Stakeholder engagement is vital for the success of sustainability practices in various contexts, including manufacturing (Bello-Pintado et al., 2023). Furthermore, the spatial structure of science and technology parks is linked to regional development and economic growth, emphasising their catalytic effects on the economy (Gimenez and Tachizawa, 2012).

2.1.3 Function of Technology Transfer Offices

The Technology Transfer Offices (TTOs) within universities play a central role in bridging the gap between academia and industry, facilitating the commercialisation of research outcomes and the transfer of intellectual property (Ng et al., 2019). These offices are instrumental in technology transfer activities, such as patenting, licencing, venture creation, and industry collaboration, with their success hinging on their organisational structure and governance mechanisms (Reischauer et al., 2021). TTOs play a vital role in fostering high-tech entrepreneurship and advancing the "triple-helix" model, which highlights collaboration between academia, industry, and government (Etzkowitz, 2003).

Furthermore, technology transfer offices serve a vital purpose in facilitating collaborative R&D projects. They aid in identifying potential research projects, managing costs, negotiating key project phases, and monitoring progress (Thomas et al., 2017). TTOs play a pivotal role in the management of knowledge transfer and commercialisation, with their governance structures varying from facilitating knowledge transfer through TTOs to establishing new entrepreneurial organisations (Baycan and Olcay, 2021). The importance of well-supported TTO is highlighted by their ability to enhance patent performance in

University Science Parks, demonstrating their significance in driving innovation and commercialisation (Ünlü et al., 2023).

2.1.4 Evaluation metrics and government perspectives

Science and technology parks (STPs) exhibit multifaceted performance, including economic impact, innovation output, and societal benefits. Key indicators and metrics are essential for evaluating STPs and guiding strategic decisions (Guadix et al., 2016). Economic indicators, such as GDP growth, job creation, and industry diversification, reveal STPs' contributions to regional development and competitiveness (Wu et al., 2020). Innovation metrics, including patent filings, technology licenses, and start-up formations, indicate knowledge creation and technology transfer capabilities (Vásquez-Urriago et al., 2014). Societal indicators, such as social inclusion, environmental sustainability, and quality of life, illustrate broader societal impacts (Fulgencio, 2017).

Government policies and international perspectives significantly influence the development, governance, and competitiveness of STPs globally (Yan et al., 2018). These policies comprise funding mechanisms and innovation incentives that shape the enabling environment for STP success (Teng et al., 2020). Comparative analyses of global STPs provide insights into diverse models and best practices, informing strategies to enhance STP effectiveness and sustainability (Albahari et al., 2018). STPs are policy-driven initiatives supported by governments as technological and innovation policy tools (Albahari et al., 2018). Their development is influenced by national and regional policies, underlining the need for a stable policy environment (Wu et al., 2020).

2.2 Evaluation of Science and Technology Parks

2.2.1 Historical overview of STPs

The historical trajectory of Science Technology Parks (STPs) can be delineated back to the latter part of the 1950s, originating in the United States with the primary objective of bridging the divide between research institutions and industrial sectors (Klepper, 2010; Mansour and Kanso, 2018). This inception marked a significant moment in the evolution of STPs, subsequently leading to their proliferation across various regions worldwide, with the notable emergence of Silicon Valley and Route 128 in the U.S. serving as exemplars of this phenomenon (Gilson, 1998).

The establishment of Science and Technology Parks on a global scale has been largely influenced by the success story of Silicon Valley. Originally known as Stanford University Science Park, Silicon Valley can be traced back to the 1950s. Subsequently, in the 1960s, Sophia Antipolis was established in Europe, followed by Tsukuba Science City in Asia, in the early 1970s. Over the past few decades, the number of STPs has significantly expanded.

According to the World Bank (2010) survey, "*Evolution of Science Parks over Time*" shown in Table 2.1;

Table 2.1: Evolution of Science Parks over Time, taken from World Bank (2010) survey

1950–1980	1990s	2000 and beyond
• Real-estate operations • Campus-like environment, selling single parcels of land • Focus on industrial recruitment • Few, if any, ties between tenants and university or federal laboratories • Little business assistance and few services provided	• Anchor with R&D facilities aligned with the industry focus of the park • Innovation centres and technology incubators are more common • Multitenant facilities constructed to accommodate smaller companies • Some support for entrepreneurs and start-up companies provided directly	• More and more mixed-use development, including commercial and residential • Increased focus and deeper service support to start-ups and entrepreneurs • Less focus on recruitment – formal accelerator space and plans for technology commercialisation roles emerging • Greater interest on the part of tenant firms in partnering with universities • Universities more committed to partnering with research park tenants • Amenities from day care to conference and recreational facilities added

The metamorphosis of STPs over time has seen them transition into strategic instruments meticulously crafted to catalyse innovation and entrepreneurship at the regional level (Tataj et al., 2022). They are acknowledged as fundamental components within the innovation frameworks of diverse nations, playing a central role in shaping nationwide innovative systems (Khan, 2018). Furthermore, the evolution of STPs has been steered by the necessity to foster the advancement of entrepreneurship and support the growth of small and medium-sized enterprises with a knowledge-centric focus (Stanković et al., 2009). These parks function as convergence points and transformative hubs for scientific and technological breakthroughs, assuming a critical role in advancing national science communication endeavours (Han et al., 2017).

Moreover, the evolution of Science and Technology Parks (STPs) has been significantly shaped by the imperative for sustainability and emergence of broader regional constructs such as technology districts (Antonelli, 2000). These developments have stimulated extensive debates surrounding the organisational paradigms of STPs, which in turn have led to the adoption of various models on a global scale (Garzoni et al., 2020). The establishment of technology districts has played an important role in promoting digital transformation, particularly in regions characterised by research delays and limited technological resources (Garzoni et al., 2020). Furthermore, the reorganisation of industrial districts, exemplified by the Wenzhou model in China, has raised concerns regarding the viability of such models in terms of sustainability (Wei et al., 2007).

Overall, the historical evolution of STPs has been propelled by the aspiration to bridge the gap between research and industry, foster innovation and entrepreneurship, drive economic growth through competition and innovation, and establish sustainable regional ecosystems that are conducive to scientific and technological advancement. These parks have evolved into key entities within the innovation landscapes of many nations.

2.2.2 STP’s role in innovation ecosystems

Science and technology parks are not merely regional initiatives, but integral components of innovation ecosystems, facilitating the translation of scientific knowledge into commercial products (Fulgencio, 2017). Policymakers recognise the importance of science parks in stimulating knowledge ecosystems within technology hotspots (Clarysse et al., 2014). The collaborative efforts within these parks are essential for driving innovative resources and nurturing emerging industries (Yan et al., 2020). In Europe, science and technology parks have emerged as vital tools for implementing innovation policies at both regional and national levels (Staszków et al., 2017). Despite their significance, the underlying role of science parks in fostering innovation, creativity, and ecosystem growth remains an area requiring further exploration (Germain et al., 2022).

The role of universities in creating innovative ecosystems is also highlighted, emphasising the unique contribution of university environments to innovation (Gontareva et al., 2022). Furthermore, the evaluation of science and technology parks using advanced systems like fuzzy expert systems underscores the multifaceted nature of these parks, which encompasses scientific, productive, and collaborative components (Nosratabadi et al., 2011).

While science and technology parks are often hailed as catalysts for innovation and economic growth, critics argue that these hubs may inadvertently exacerbate inequality by concentrating resources and opportunities in specific geographic areas (Tataj et al., 2022). This concentration can lead to a scenario where innovation is primarily fostered within these parks, hindering the development of innovative ecosystems outside of these hubs and widening regional disparities in economic development.

One perspective suggests that high-technology incubators, which are often part of science and technology parks, may address an innovation market failure by focusing on technologies with uncertain commercial value (Phan et al., 2005). However, this selective approach could inadvertently exclude innovations that do not fit within the high-technology framework, potentially leaving out valuable contributions from other sectors (Phan et al., 2005). Moreover, the concept of science parks as knowledge organisations closely tied to universities and businesses may inadvertently create a divide between those within the park ecosystem and those outside of it. This division could limit the diffusion of knowledge and technology to broader communities, further deepening the disparities in access to innovation and economic opportunities (Hansson, 2007).

Critics also argue that the development of science and technology parks may contribute to regional inequalities by concentrating resources and opportunities in specific areas, neglecting the potential for innovation in other regions (Macdonald and Deng, 2004; Spithoven, 2015). This concentration of resources may hinder regions outside these parks from competing in innovation and economic development, thereby exacerbating the disparity between the technology-rich and technology-poor regions (Goldstein and Luger, 1990). Moreover, emphasising the role of science parks in fostering innovation may inadvertently perpetuate existing inequalities by directing resources towards already advantaged areas, leading to flourishing regions with established parks, while others struggle to attract investment and innovation (Khavandkar et al., 2016).

In summary, science and technology parks undoubtedly play a significant role in stimulating innovation and economic expansion. Nevertheless, they have also given rise to pressing concerns about regional disparities and the concentration of resources. Although these parks offer numerous advantages such as facilitating collaboration among universities, businesses, and emerging industries, their potential to widen disparities in innovation opportunities between regions requires careful examination.

2.3 Collaborative Dynamics and Firm Impact in STPs

2.3.1 Collaboration of NTBFs, universities, and large firms within STPs

Collaborations among NTBFs, universities, and large firms in science and technology parks are essential for driving innovation and economic growth. Studies have shown that these partnerships lead to benefits, such as inter-firm networking, connections between universities and research institutions, and technological advancements within the park (Myoken, 2011). Furthermore, the proximity of firms to universities, due to knowledge spillovers, enhances innovation performance (Han, 2017; Audretsch et al., 2017). The importance of university-industry collaborations has been widely examined, and the results consistently demonstrate their capacity to stimulate innovation and commercialisation in various industries (Dezi et al., 2018; González-Pernía et al., 2014). These collaborations facilitate knowledge exchange, scientific advancements, and the emergence of novel technologies that benefit both the academic and industrial sectors (Macdonald and Deng, 2004).

In recent years, Science and Technology Parks (STPs) have become indispensable components of the innovation ecosystem, complementing the role of university-industry partnerships (Alibegović et al., 2022). These parks offer essential networking, funding access, and business support services for the growth of technology-based start-ups and small and medium-sized enterprises (SMEs), which in turn support national goals (Porter, 1990). Furthermore, STPs attract and nurture new technology-based firms (NTBFs) engaged in advanced research and innovation (Albahari et al., 2018). By facilitating interactions among academia, industry, and the government, STPs create a collaborative ecosystem that encourages knowledge sharing, strategic partnerships, and technological advancement. This environment benefits individual firms and enhances the competitiveness and sustainability of the regional innovation systems (Nauwelaers et al., 2019). Collaborative governance models emphasise the importance of repeated interactions and intensive collaborative processes in improving information exchange and decision-making quality (Ansell and Gash, 2008; Scott, 2015).

According to Belderbos et al. (2004), cooperative R&D with competitors and suppliers typically results in incremental innovation that enhances productivity. By contrast, collaborations with universities and competitors are more effective in generating radical innovations that boost sales and growth. Arora et al. (2018) suggested a potential decline in the focus on novel knowledge production within corporate R&D, prompting the need to examine how partnerships with academic institutions contribute to innovation. Kafouros et al. (2015) emphasise the significance of academic collaborations in improving firms' innovation performance, particularly in developed countries. Although Balle et al. (2019) acknowledged the challenges of joint technology development between universities and companies, they highlighted the potential benefits of such partnerships. Polidoro et al. (2022) identify the complexities of knowledge sharing in Science Technology Parks (STPs), including the risk of knowledge spillovers benefiting competitors. Bruneel et al. (2016) explore the impact of financial slack on knowledge acquisition from universities, underscoring the challenges in leveraging collaborations for innovation success.

A study conducted by Rydehell et al. (2019) suggested that proximity to universities may hold greater importance in fostering collaboration and knowledge transfer than proximity within Science and Technology Parks (STPs). This finding challenges the conventional belief that physical closeness is a key determinant of successful partnerships in these ecosystems. Castrogiovanni et al. (2012) emphasise that small and medium enterprises (SMEs) use service intermediaries for R&D, which is influenced by various SME specific characteristics. The relationship between SMEs and technology centres or universities is not always straightforward, as some SMEs have a positive association with export activities, while others exhibit a negative correlation with university collaborations (Castrogiovanni et al., 2012).

In summary, although partnerships among New Technology-Based Firms (NTBFs), universities, and large enterprises within STPs offer numerous advantages, it is essential to consider the complexities and potential drawbacks highlighted by various perspectives to gain a comprehensive understanding of the factors affecting decision-making in these ecosystems. A deeper understanding of collaborative dynamics in STPs is essential for optimising these relationships and driving innovation and economic growth.

2.3.2 Influence of varying numbers of large firms within STPs on performance

Research has examined the influence of major corporations on the productivity of Science and Technology Parks (STPs), considering various aspects. Todo et al. (2011) highlighted that the presence of significant corporations in STPs can lead to increased knowledge spillovers, fostering collaboration and innovation. This is supported by Montoro-Sánchez et al. (2011), who demonstrated that knowledge spillovers have a positive effect on a firm's propensity to innovate and engage in collaborative R&D agreements within STPs. Additionally, Lööf and Nabavi (2015) emphasised that a firm's performance is influenced not only by technological closeness to other firms but also by geographical proximity, highlighting the importance of knowledge spillovers in enhancing productivity and innovation within STPs.

The presence of large companies within Science and Technology Parks (STPs) can attract additional resources and investments because of their greater financial capabilities, which benefit start-ups and smaller businesses. This influx of resources can enhance innovative ecosystems and improve performance. This aligns with the findings of Clarysse et al. (2014), who emphasised the importance of financial support in driving innovative output within ecosystems. Additionally, Azzam et al. (2017) highlighted how patent licensing can facilitate knowledge transfer and commercialisation between large and small firms, further supporting the idea that large firms can contribute to the success of smaller entities within the ecosystem (Liu et al., 2022).

Furthermore, Poonjan and Tanner (2020) and Poonjan et al. (2022) emphasise the importance of robust industrial clustering or the presence of major high-tech companies in promoting the effectiveness of science and technology parks, especially when the STP's strategic focus aligns with local industries (Todo et al., 2011; Audretsch et al., 2017). The collaborative dynamic between large and smaller firms within Science and Technology Parks (STPs), leading to a symbiotic relationship that promotes innovation and fosters growth, is a critical aspect of the ecosystem (Jafarnejad et al., 2013).

According to the IASP Survey (2022), the strong connection between Areas of Innovation/Science and Technology Parks (AOIs/STPs) and their local areas is demonstrated by the fact that 41.4% of companies based in the parks are of local origin. This also highlights the importance of these companies as local innovation actors. Additionally, it is noteworthy that 84.5% of the resident companies in AOIs/STPs are micro and small businesses, employing fewer than 10 and 50 people respectively.

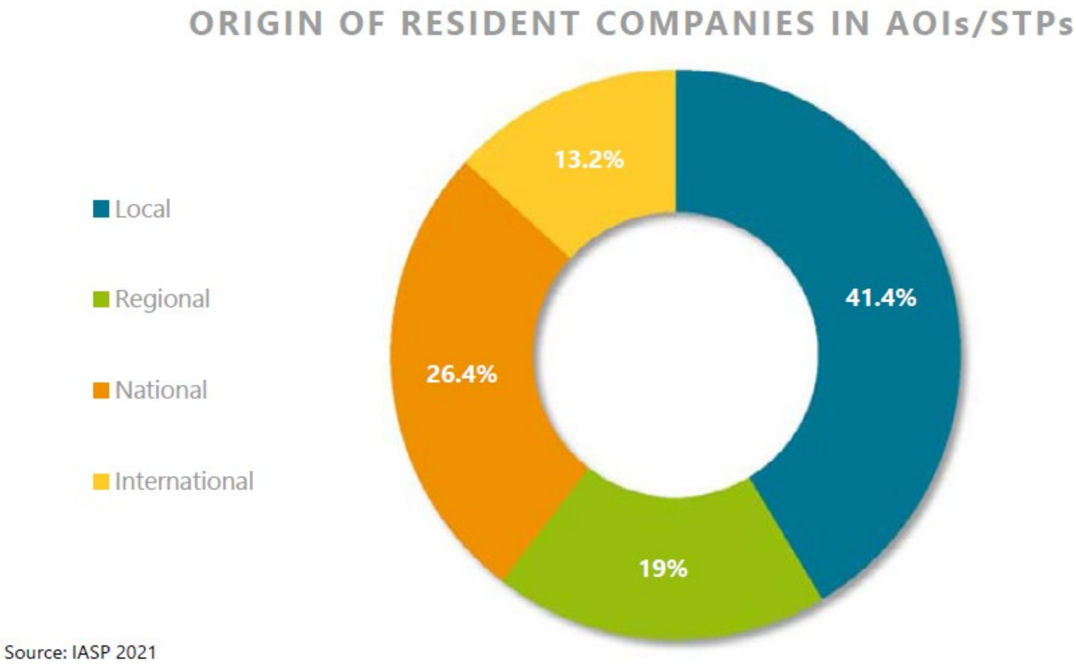


Figure 2.1: Origin of Resident Companies in AOIs/STPs (IASP Survey, 2022)

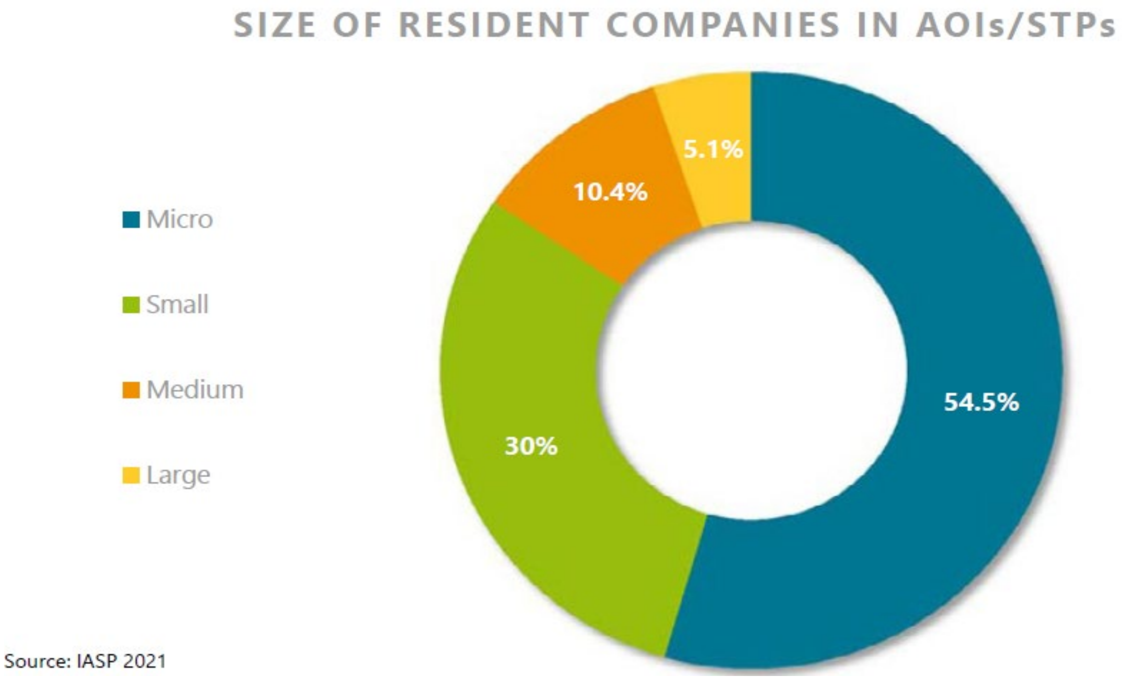


Figure 2.2: Size of Resident Companies in AOIs/STPs (IASP Survey, 2022)

The IASP Survey conducted in 2022 also indicates that multinational companies are not the dominant entities in AOIs/STPs.

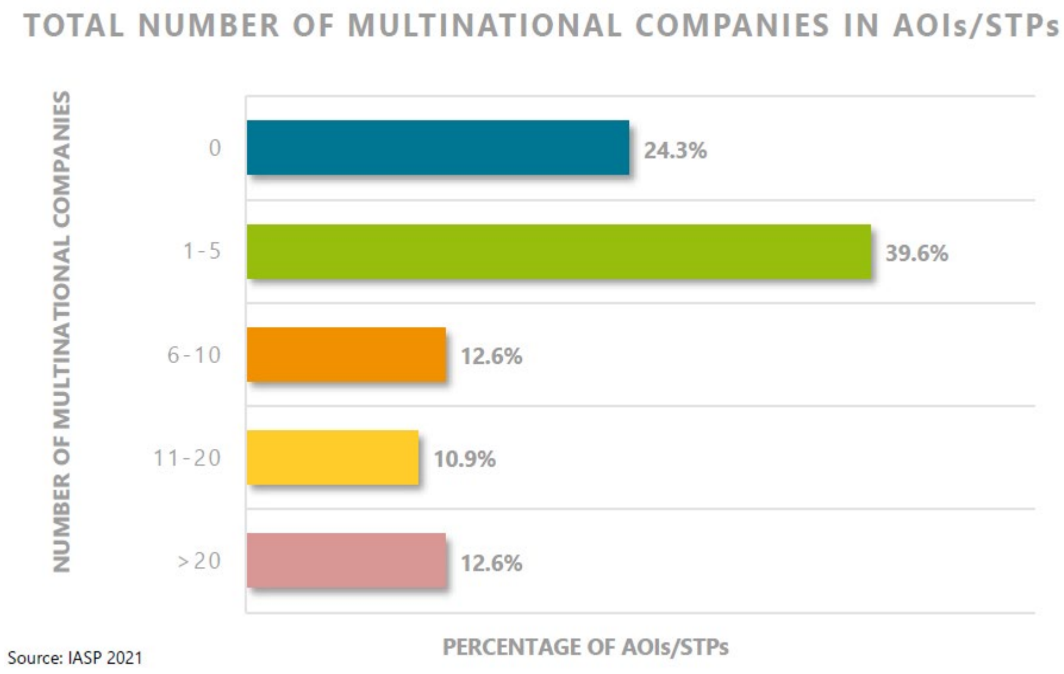


Figure 2.3: Total Number of Multinational Companies in AOIs/STPs (IASP Survey, 2022)

Although science and technology parks are commonly believed to have a favourable impact on knowledge spillovers and innovation due to the presence of significant corporations, there are conflicting views on this matter. Some scholars, such as Shukla et al. (2020), argue that the influence of local institutions on multinational corporations in foreign markets may be exaggerated. This suggests that the actions of large corporations within STPs may not solely depend on the local environment but could also be influenced by various external factors beyond the park's boundaries.

Research on the significance of organisational architecture within STP environments indicates that the presence of a number of large firms can impact transaction costs (Al-Kfairy et al., 2020). Specifically, having more than two large firms can lead to increased transaction costs within the STPs. This underscores the importance of understanding and optimising the organisational structure within STPs to manage transaction costs effectively.

In summary, the influence of a varying number of large firms in Science and Technology Parks (STPs) on performance is a complex issue with multiple facets. Although studies suggest that the concentration of large firms can bring about positive outcomes, such as knowledge dissemination, resource access, and fostering an innovative environment in

STPs, it is important to exercise caution due to conflicting research results and potential adverse effects on co-operation. To establish an optimal equilibrium between the presence of large firms and the needs of smaller businesses, researchers and policymakers must carefully consider each STP's unique context and operational dynamics.

2.3.3 Contrasting dynamics between mature and developing STPs

As STPs progress from start-up to early maturity and full maturity, their architecture becomes increasingly important for adapting to changing innovation environments (Al-Kfairy et al., 2020). Assessing the maturity levels of Science and Technology Parks in developing regions is essential to identify areas for improvement and create strategies for knowledge exchange (Chan and Lau, 2005). STPs face various challenges, including the need to adapt continuously to evolving innovation environments, low success rates, and the demand for professionals with diverse skill sets. The maturity level of STPs varies and influences their impact on the local economy and innovation ecosystems (Chan and Lau, 2005).

Correia et al. (2021) stressed the importance of assessing the maturity level of STPs, especially in emerging regions such as Latin America, to identify areas for improvement and plan future actions for knowledge transfer. It is essential to understand the evolution of STPs from incubation to maturity, as it can affect their innovative capacity and the exchange of knowledge among firms situated within parks (Correia et al., 2021; Díez-Vial and Montoro-Sánchez, 2017).

Established Science and Technology Parks (STPs) cultivate a robust network of relationships between businesses and institutions, stimulating the growth of start-ups (Díez-Vial and Fernández-Olmos, 2015). These fully developed parks provide firms with numerous advantages including enhanced credibility and accessibility to clients and other enterprises (Guadix et al., 2016). Furthermore, mature STPs are associated with success variables that contribute to the overall success of firms situated within these parks (Guadix et al., 2016). Developing effective strategies for STP operators to support hosted companies and start-ups at different maturity stages is essential to enhance performance (Lee et al., 2021). Established STPs facilitate strong networks between businesses and institutions, fostering the growth of start-ups (Poonjan and Tanner, 2020). On the other hand, emerging STPs primarily focus on fostering young technology-based start-ups (Ullah et al., 2023).

The findings of the IASP 2022 Survey reveal that North America and Europe are at the forefront of the industry in terms of maturity, with a considerable number of mature areas and parks being over 26 years old. In these regions, a substantial proportion of AOIs/STPs are between 26 and 40 years old, with North America having 10% that are over 40 years old, and nearly half of the European respondents (47.3%) falling into this age range. On the other hand, Eurasia has witnessed the highest number of AOIs/STPs established in the past five years.

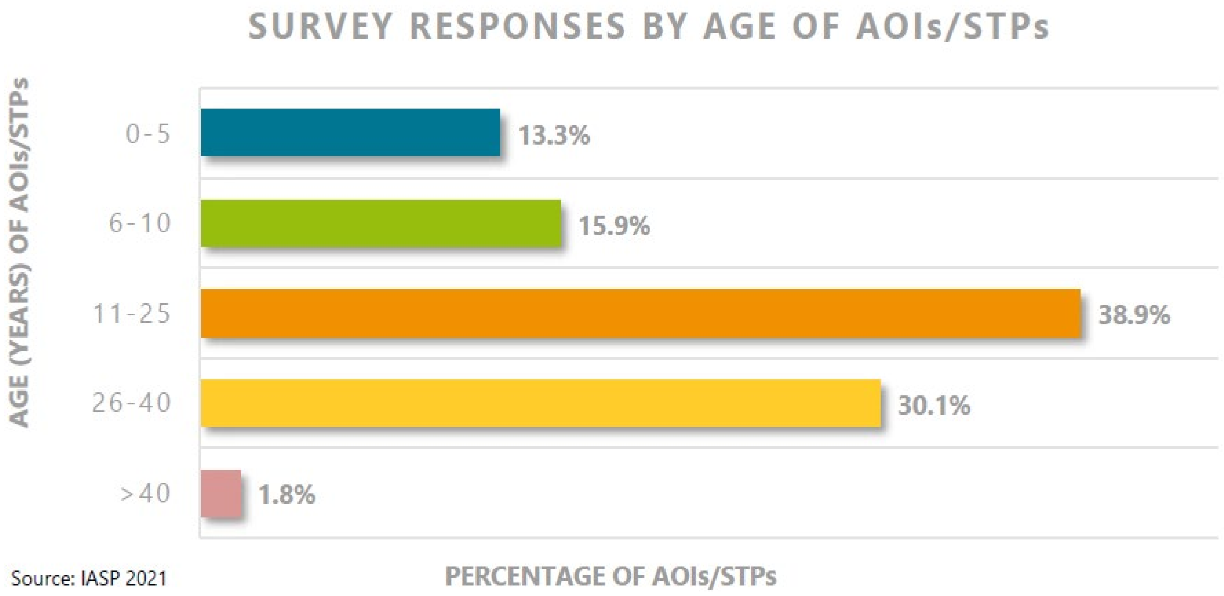


Figure 2.4: Age of AOIs/STPs by IASP Survey Report 2022

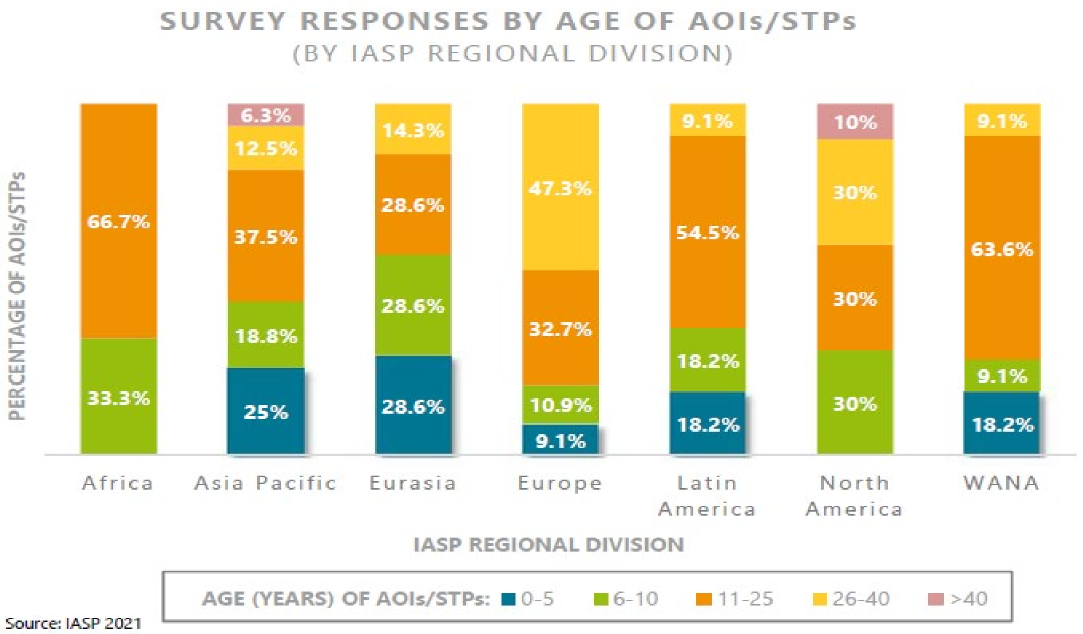


Figure 2.5: Age of AOIs/STPs by Regional Division (IASP Survey, 2022)

To understand the dynamics between mature and developing Science and Technology Parks (STPs) and the factors influencing them, a thorough analysis of various aspects is necessary. Factors such as university involvement, internal management, regional development, and resource dependencies play a vital role in shaping the effectiveness and impact of STPs on innovation and economic development (Sudiana et al., 2020; Zhang and Sonobe, 2011; Wang and Tu, 2023).

2.4 Geographic Clustering and Interaction Dynamics in STPs

2.4.1 Factors Influencing Geographic Clustering of STPs

Research has demonstrated that the close proximity of companies within science and technology parks facilitates increased interaction among high-tech professionals, resulting in the growth of professional networks and fostering innovation (Hu, 2008). The spatial concentration of firms within STPs facilitates the exchange of knowledge and fosters co-operation, ultimately benefiting the competitive edge and performance of enterprises within the cluster (Fioravanti et al., 2023). Furthermore, the widespread acceptance of science and technology parks across the world has been driven by their demonstrable success in supporting the expansion of cutting-edge industries and promoting economic development at the regional level (Yan and Chien, 2013).

According to Fioravanti et al. (2023), academic knowledge, co-operation, ties with institutions, workforce mobility, and geographical proximity are key factors that have an impact on the competitiveness and overall performance of businesses in STPs, considering internal and regional aspects. The establishment of science and technology parks is intended to cultivate knowledge-based economic clusters, underscoring the significance of knowledge transfer and innovation within these contexts (Sudiana and Hendayani, 2020). Overall, STPs act as interconnected systems of relationships among geographically close businesses and institutions, promoting the growth of start-ups and nurturing innovation (Díez-Vial and Fernández-Olmos, 2015).

While some researchers argue that the success of industrial clusters and innovation networks is not solely dependent on geographic proximity (Boschma, 2005; Bathelt et al., 2004). According to Furman et al. (2002), the factors that contribute to a nation's innovative capacity are complex and depend on a range of factors, such as input supply, local demand conditions, and the relationships between related industries and competitive rivalry. This perspective suggests that factors beyond physical proximity, including market dynamics and industry structure, have a significant impact on fostering innovation and competitiveness.

Moreover, the notion of innovation networks and technological learning within high-tech clusters underscores the positive and direct influence of network relationships and centrality on the acquisition and utilisation of technology (Pan et al., 2019). It suggests that the quality and organisation of relationships within a network might be more influential than physical proximity in fostering innovation achievements (Mondal and Mellor, 2024)

In summary, while science and technology parks (STPs) provide geographic proximity that fosters interaction and innovation, the success of these ecosystems also depends on the quality of collaboration, institutional ties, and network relationships. It is a combination of spatial concentration and strategic management of connections and resources that drives effective innovation. Therefore, in addition to physical proximity, it is essential to understand the organisational and relational dynamics within STPs to enhance competitiveness and drive economic development.

2.4.2 Impact on University-NTBF interaction dynamics within STPs

The interactions between universities and New Technology-Based Firms (NTBFs) within Science and Technology Parks (STPs) are significantly influenced by a multitude of factors that shape collaboration, innovation, and knowledge exchange. Comprehending these influences is vital for maximising outcomes and cultivating a favourable environment that promotes growth and development within STPs.

Bruneel et al. (2010) highlighted the need to reduce obstacles in university-business collaborations by identifying the factors that contribute to such barriers. Montoro-Sánchez et al. (2011) further supported this by demonstrating that knowledge spillovers can enhance firms' innovation and engagement in R&D within science and technology parks. This underscores the importance of knowledge exchange in fostering effective partnerships among STPs. The significance of the location of NTBFs within STPs influences university-industry relationships. Oostrom et al. (2019) noted that NTBFs located in science parks are more likely to engage in joint research with universities, emphasising the roles of proximity and absorptive capacity. Additionally, Ganotakis and Love (2011) examined the impact of R&D and product innovation on the export activities of UK NTBFs, illustrating the link between innovation and market expansion.

Universities have a significant impact on R&D expenditure in NTBFs, which in turn affects collaboration within STPs through strategic and entrepreneurial dynamics, as highlighted by Lynskey (2016). This relationship enhances R&D capability and innovation. Top-tier research universities play a key role in generating scientific and technological advancements, leading to the establishment of high-tech firms within STPs (Inamete, 2015). This underscores the central role of universities in fostering innovation and NTBF growth within the STP ecosystem. Furthermore, university-industry collaborations within STPs can result in increased patent filings, influential publications, and competitive advantages (Eryılmaz, 2017), highlighting the mutual benefits of such partnerships. Talab et al. (2020) stressed the importance of understanding knowledge collaboration behaviours between universities to optimise inter-organisational collaborations.

In line with the IASP Survey carried out in 2022, nearly half (56.6%) of the participants (AOIs/STPs) were positioned on a university campus or in close proximity to one. Moreover, a considerable proportion (24.8%) of science parks have at least one university within a 5km radius, thereby facilitating the transfer of knowledge between academia and industry (IASP Survey, 2022).

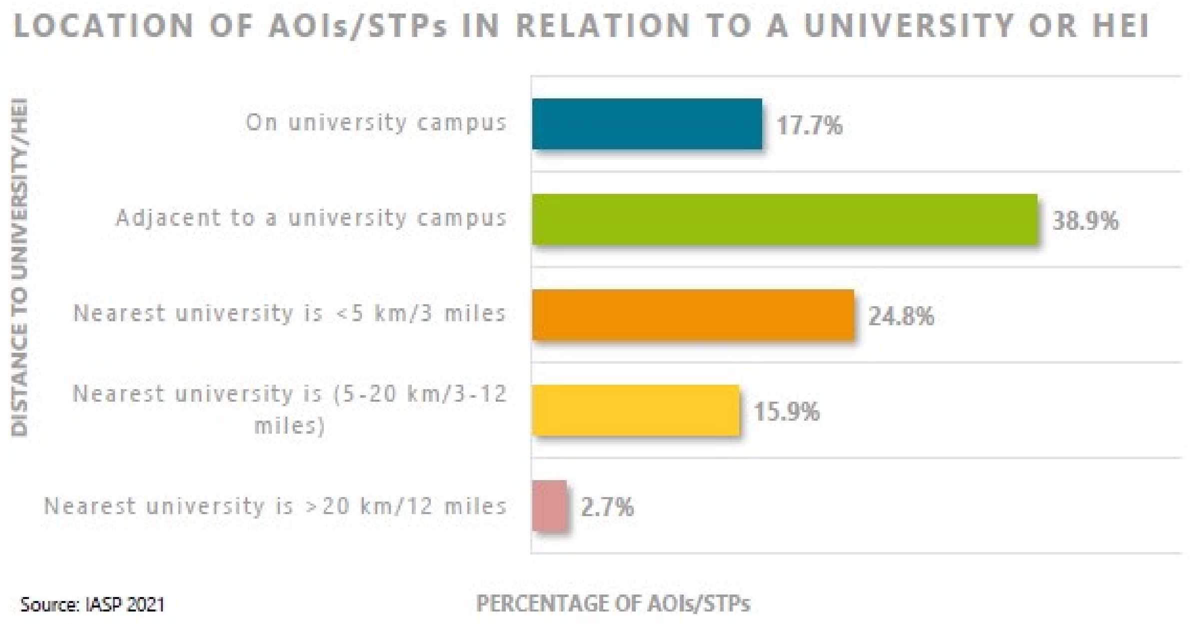


Figure 2.6: Location of AOIs/STPs in Relation to a University or HEI (IASP Survey, 2022)

The relationships formed between universities and science parks can take various forms, and it is common for multiple types of links to be established simultaneously. This collaboration enhances the chance of success and increases the potential for positive outcomes. According to the survey, 86.7% of the respondents agreed with universities, while 59.3% shared some form of scientific infrastructure and/or services with a university (IASP Survey, 2022).

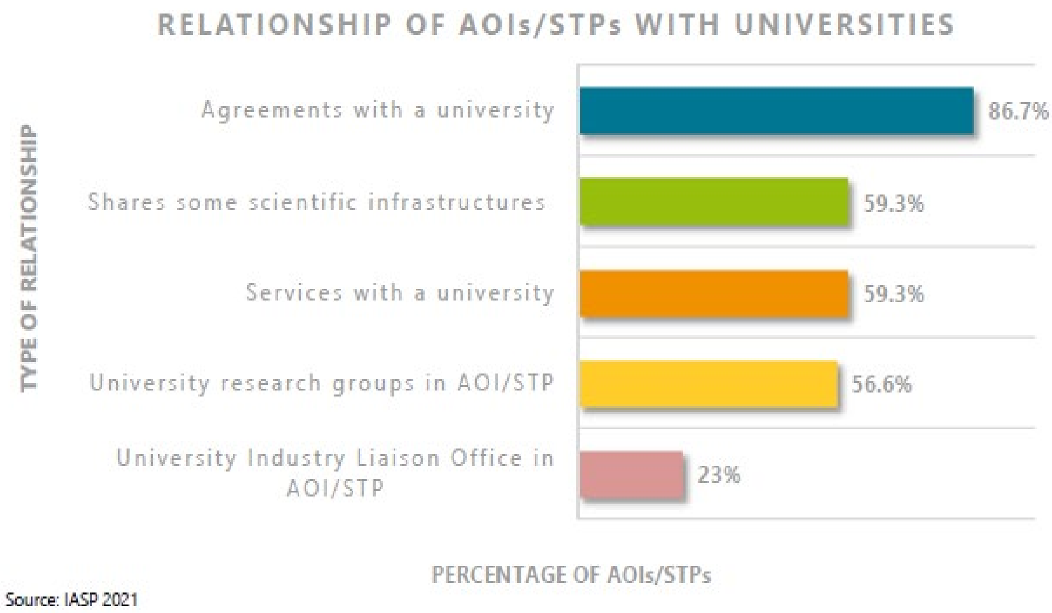


Figure 2.7: Relationship of AOIs/STPs with University (IASP Survey, 2022)

Universities play a pivotal role in facilitating knowledge exchange and fostering collaborative innovation with NTBFs, which serve as essential drivers of economic growth and a culture of innovation (Li, 2010). According to Wang and Yu (2019), such collaboration promotes the integration of production and education, thereby bringing academia and industry together. This integration is vital for maintaining the connections between universities and entrepreneurs. Although effective communication is recognised as essential for university-firm relationships (Silva and Rossi, 2018), numerous communication barriers exist, impeding the acquisition and co-creation of valuable knowledge and affecting the quality of collaboration. Furthermore, the notion that universities and firms are non-competitors (Silva and Rossi, 2018) may overlook competitive dynamics, in which intellectual property and market competition hold significant importance.

Collaboration between universities and NTBFs is widely recognised as beneficial (Baxter et al., 2022), however, there are challenges that need to be addressed to swiftly transform inventions into marketable products. Baxter et al. (2022) noted that collaborative relationships can accelerate discoveries, regulatory barriers, market demands, and financial constraints can hinder these relationships. Moreover, Melnychuk et al. (2021) emphasise that university-industry collaborations can enhance R&D performance, but this is not always guaranteed. Conflicting research priorities, divergent timelines, and resource allocation difficulties can impede the efficiency of these collaborations, thus affecting the outcomes of company R&D. Additionally, while geographic proximity often promotes collaboration (Alpaydın and Fitjar, 2021), nearby businesses and academic institutions may still face challenges in forming successful partnerships because of organisational disparities and conflicting goals.

In summary, the interactions between universities and NTBFs in STPs are intricate and changeable and are influenced by various elements such as intellectual property sharing, geographic vicinity, and unified innovation endeavours. Although scholarly works frequently extol the virtues of collaboration between these entities, it is important to recognise and tackle the potential difficulties and constraints that can impede their effectiveness in fostering invention and knowledge dissemination.

2.5 Technology Transfer Offices (TTOs) at universities

2.5.1 Functions and roles of TTOs in facilitating technology transfer

The Technology Transfer Offices (TTOs) at universities are instrumental in facilitating technology transfer within Science and Technology Parks (STPs). The exchange of knowledge and technology between academia and industry has been thoroughly investigated, revealing the mechanisms through which these transfers occur (Markman et al., 2005). Previous research has primarily focused on elite research universities, but there is an increasing need to examine the broader range of TTO activities and their influence on technology transfer within STPs (Phan et al., 2005).

Technology Transfer Offices (TTOs) act as intermediaries between academia and industry, facilitating the commercialisation of academic research and driving innovation (Clayton et al., 2018; Sutopo et al., 2022). They manage and protect the intellectual property created within universities, which is essential for effective technology transfer (Siegel et al., 2003). A key function of TTOs is to maintain relationships among stakeholders, including researchers, students, businesses, and government agencies (Cucino et al., 2022). Moreover, TTOs are a central link in facilitating the dissemination of innovation and the construction of cutting-edge technology infrastructure (Siegel et al., 2008). Their role in technology transfer and commercialisation is important because they bridge the gap between research institutions and industry, facilitating the translation of scientific discoveries into practical applications and marketable products (Ahmedova, 2020). They are vital in transforming business requirements into technology demand, and actively stimulate economic growth by overseeing technology transfer processes (Karanikić, 2022). This involves identifying opportunities for innovation and strategically aligning technological solutions with the business objectives.

The success of TTOs is contingent upon their capacity to efficiently capture and transfer value throughout the knowledge and technology transfer process, ensuring that both the inventors and the end-users realise the benefits of research and innovation. To maximise the value derived from knowledge and technology transfer, Technology Transfer Offices (TTOs) must not only prioritise facilitating the transfer of technology from research institutions to industry but also foster collaboration and knowledge exchange among various stakeholders. TTOs also play a critical role in the formation of university start-ups by providing support for new venture creation and promoting creativity (Chugh, 2013).

Figure 2.8 on the next page depicts the Technology Transfer Process in a circular flowchart, showing the essential stages from invention to financial returns. The process commences with the invention and progresses to invention disclosure, where the details are formally documented. The potential and feasibility of this invention were subsequently assessed. If deemed valuable, it advances to the protection stage to secure intellectual property rights such as patents. In the marketing phase, the invention is promoted to potential industry partners. This is followed by licencing, in which agreements are made for the external use of technology. The process concludes with financial returns, generating revenue from licenced technology, which in turn supports further innovation. The circular layout emphasises the continuous and interconnected nature of this process.

Figure 2.8: The process of technology transfer. Source: (CDC, 2024).

In summary, Technology Transfer Offices (TTOs) are essential entities that connect academia and industry within the realm of Science and Technology Parks (STPs). Their functions include managing intellectual property, promoting collaboration, and facilitating innovation, all of which contribute to seamless technology transfer and commercialisation. Moreover, by fostering relationships and assisting start-up ventures, TTOs play a pivotal role in driving economic growth and entrepreneurship, thereby significantly impacting both academic and commercial sectors.

2.5.2 Implications of different organizational structures within TTOs on their performance

Organisational structures within Technology Transfer Offices (TTOs) are of paramount importance in determining their performance within universities and science and technology parks. Numerous studies have emphasised the significance of organisational factors in enhancing TTO performance, highlighting the importance of "soft" factors such as empowerment and engagement in improving TTO performance (Bercovitz and Feldman, 2008). A supportive and empowering organisational structure can facilitate improved outcomes in technology transfer activities. Cucino et al. (2022) underscore the importance of balancing the "soft" aspects of total quality management to enhance TTO performance.

This suggests that, beyond focusing solely on numbers, factors such as empowerment are essential for improving TTO effectiveness. Developing strong collaborative networks and forming strategic alliances are essential to the success of Technology Transfer Offices (TTOs) operating within Science and Technology Parks (STPs). A well-structured organisation, in conjunction with strategic partnerships, is critical in enhancing the performance of TTOs in university and STP settings (Bandarian, R., 2018). These collaborations facilitate efficient technology transfer and offer valuable resources, knowledge-sharing opportunities, and empowerment to TTOs. Consequently, the technology transfer activities within STPs have become more effective, resulting in improved outcomes.

Moreover, technology transfer offices are established in universities to act as boundary spanners in the pre-spin-off process and to facilitate technology transfer while managing ambidexterity (Huyghe et al., 2014). These offices are essential for promoting and supporting relationships between different stakeholders, which is critical for successful technology-transfer activities. Furthermore, Soares et al. (2020) emphasise the role of TTOs in building sustainable development and highlight the importance of organisational maturity levels. This suggests that the organisational structure of TTOs should be aligned with sustainable practices to ensure long-term success within the science and technology park sectors (Soares et al., 2020). The organisational structure of TTOs is important for their effectiveness in technology transfer and sustainable development, and should be designed to facilitate collaboration and knowledge sharing among researchers, industry partners, and other stakeholders (Bruun and Mefford, 1996).

Žmuidzinaitė et al. (2021) emphasise the importance of technology transfer offices in innovation ecosystems, underlining their role in enhancing technology transfer activities within universities. Technology transfer offices can exhibit diverse organisational configurations and frameworks, underscoring the need for tailored organisational arrangements that are appropriately suited to specific circumstances (Karanikić, 2022). This suggests that a flexible organisational structure that adapts to the requirements of the university and science and technology park environment is essential for optimal performance (Karanikić, 2022). To ensure the effective management of TTOs and their impact on innovation ecosystems, it is vital to adopt a strategic approach that aligns with the objectives of the university and the broader innovation ecosystem. The emphasis on the importance of flexible organisational structures and strategic approaches highlights the intricate nature of technology transfer activities and the significance of tailored setups to maximise impact.

In addition, organisational factors such as human resources, industry research demand, R&D budget of the university, and economic uncertainty have been identified as influential factors on the performance of TTOs (Ustundag et al., 2011). These elements play a significant role in shaping the effectiveness of technology transfer activities within TTOs. Moreover, Sengupta and Ray (2017) discuss the importance of having a clear organisational structure and defined roles within TTOs, as organisational sub-units within universities have their own mandates and autonomy. This implies that the organisational structure and resource allocation within TTOs are pivotal for their success in facilitating technology transfer and innovation.

In summary, the organisational structure of Technology Transfer Offices (TTOs) plays a critical role in determining their performance within the university and STPs. The success of TTOs is closely linked to their organisational structure, which must promote empowerment, engagement, sustainability, flexibility, and clear roles to maximize their effectiveness in facilitating technology transfer and commercialisation activities within academic and park settings. It is essential for TTOs to continuously assess and adjust their organisational structures to effectively respond to the evolving demands of the technology transfer landscape. Furthermore, fostering collaboration and communication within the TTO and across the academic and park community can enhance the impact of TTOs.

2.5.3 Advancing the Triple-Helix Model for High-Tech Entrepreneurship

The triple-helix model, which brings together academia, industry, and government, has demonstrated a marked impact on high-tech entrepreneurship in Science and Technology Parks (STPs) and has been subject to extensive research for its critical role in fostering innovation and driving economic growth (Etzkowitz and Leydesdorff, 1995; Etzkowitz, 2003). Cai and Etzkowitz (2020) highlighted the vital role of universities in facilitating societal transitions from industrial to knowledge-based economies, underlining the significance of academia in driving innovation and entrepreneurship. This emphasises the essential part that universities play in the triple-helix model, as they contribute knowledge, research, and talent to the innovation ecosystem. Galvao et al. (2019) discuss how the triple-helix model promotes innovation policy through collective entrepreneurship, emphasising the collaborative efforts between companies, governments, and academics. This collaborative approach fosters an environment conducive to high-tech entrepreneurship within STPs by leveraging the strength of each sector.

According to Sarpong et al. (2017), a collaborative effort involving universities, industry, and the government is necessary to implement a hybrid triple-helix model of innovation, adapt to the evolving dynamics of high-tech entrepreneurship, and foster a conducive environment for innovation. Feola et al. (2019) highlight the influence of the triple-helix model and the theory of planned behaviour on young researchers' entrepreneurial intentions, which is essential for understanding the factors driving academic spin-offs and ventures in science and technology parks. Zhang et al. (2021) stressed the importance of government initiatives, such as the development of high-tech industries and science and technology parks, in promoting economic growth and entrepreneurship. Li and Zhang (2010) emphasise the role of R&D and innovation in high-tech enterprise parks, noting these parks as hubs for accelerating innovation and technological advancement.

Badzińska (2021) emphasises the role of academic entrepreneurship and research commercialisation in enabling universities and research institutes to contribute to technological entrepreneurship through innovative products and services. This collaboration between academia and industry enhances the innovation ecosystem in science and technology parks. Sala et al. (2022) stress the significance of adaptability and creativity in entrepreneurial pivoting for tech start-ups, which, in turn, influences high-tech entrepreneurship within STPs. It is essential to understand the stages of technology entrepreneurship and the importance of pivoting to meet market demands for start-up success in these settings. The development of the triple-helix model to promote high-tech entrepreneurship in STPs involves various factors, including government support, immigrant entrepreneurship, academic collaboration, and entrepreneurial adaptability. Integrating these elements and comprehending the dynamics of the innovation ecosystem enables STPs to foster sustainable, high-tech entrepreneurship and drive economic growth.

However, some contend that the triple-helix model may confront challenges in promoting high-tech entrepreneurship in Science and Technology Parks (STPs). Etzkowitz (2003) highlighted potential obstacles such as government bureaucracy, insufficient support for immigrant entrepreneurship, restricted academic collaboration prospects, and entrepreneurs' difficulties in adapting to swiftly changing market circumstances. These factors could impede the effectiveness of STPs in nurturing sustainable high-tech entrepreneurship and driving economic expansion. One perspective, highlighted by Cai and Etzkowitz (2020), suggests a balanced model of the triple helix that considers two opposing viewpoints. The first is the statist model, wherein the government exercises control over academia, industry, and the government. The second is the laissez-faire model, where the sectors are separate and minimally interact. This perspective questions the integrated approach of the triple-helix model and argues that strong boundaries between academia, industry, and the government may hinder innovation.

According to Carayannis et al. (2012), the triple-helix model underpins the significance of knowledge production and innovation in the economy and aligns well with the tenets of the knowledge economy. This suggests that the model is highly relevant to the fast-paced knowledge-based economy, casting doubt on the necessity of alternative models. However, Cai (2014) points out that the triple-helix model was primarily developed from the experiences of advanced Western economies, raising concerns about its applicability in non-Western contexts and implying potential limitations in diverse socioeconomic environments. Steiber and Alänge (2013) acknowledge the theoretical value of triple-helix interactions but highlight the inadequacies in comprehending the interactions and specific actors within the university, industry, and government sectors, emphasising the need for a more detailed understanding of these dynamics. Mineiro et al. (2021) delve into the nonlinear nature of innovation models in STPs, suggesting that the rigid triple-helix framework may not always be suitable for the complex interactions and diverse actors in these environments. Noya et al. (2023) emphasise the role of SMEs in fostering innovation within the triple-helix ecosystem, but they also identify obstacles such as limited networking and weak social capital among SMEs, as reported by Nakwa and Zawdie (2016), which may impede effective implementation of the model in STPs, underscoring the need for tailored strategies to support diverse actors in these innovation hubs.

Jovanović et al. (2022) presented a table that served to summarise the different methods employed to assess triple-helix performance, with the aim of identifying gaps in existing methodologies.

Table 2.2: Existing Measures of Triple-Helix Performance, taken from Jovanović et al. (2022)

What is measured:	References	Triple Helix actors evaluated	Pros	Cons
Patent activity	OECD (2020a, b), Meyer et al. (2003)	All three actors	Important measure of R&D performance	Difficulties in the patenting process Does not evaluate overall Triple Helix performance

Bibliometrics & publishing activity	Villanueva-Felez et al. (2013); Xu et al. (2015); Priego (2006)	University, Industry	Offers insight into R&D cooperation of industry and academia	Evaluates only output measures. Does not evaluate government performance Does not evaluate overall Triple Helix performance
Academic spin-offs	Lawton Smith and Ho (2006); Fini et al. (2017); Samo and Huda (2019)	University	Indicates the level of entrepreneurial orientation of universities within a selected country	Limited data on the number of spinoff within a country Does not evaluate overall Triple Helix performance
Mutual information	Leydesdorff (2003); Leydesdorff et al. (2006); Leydesdorff and Fritsch (2006); Leydesdorff and Sun (2009); etc	All three actors	Evaluates synergy strength and interactions within a system	Based solely on bibliometric analysis. Does not evaluate any other type of interaction
Interrelations	Villanueva-Felez et al. (2013)	All three actors	Evaluates strength of collaboration between academia and non-academic environment	Focused only on social networks. Neglects other important aspects of the Triple Helix model
Multivariate approaches	Tijssen (2006); Tarnawska and Mavroeidis (2015); Marinković et al. (2016); Egorov and Pospelova (2019); Ivanova et al. (2019); Jovanović et al. (2020)	All three actors	Combines disparate aspects of Triple Helix performance	Effectiveness depends on the aggregation methods selected Sensitive to the selection of indicators Missing data within some systems

In summary, the Triple-Helix model has played a significant role in promoting innovation by facilitating collaboration between universities, industries, and governments. However, its application in STPs may be hindered by a number of factors, such as the evolving nature of innovation ecosystems, the need for greater stakeholder engagement, the nonlinear dynamics of innovation models, and the challenges faced by SMEs. Critics of the triple-helix model argue for stronger boundaries between academia, industry, and government, question its applicability to non-Western contexts, and highlight the limitations of understanding the actual interactions within the model. These diverse viewpoints contribute to a more nuanced understanding of the Triple-Helix model's effectiveness and limitations in fostering innovation and entrepreneurship in STPs.

2.6 Evaluating Success Metrics in Science and Technology Parks

2.6.1 Key indicators and metrics for measuring success

Evaluating the success of Science and Technology Parks (STPs) presents challenges due to the diverse nature of these innovation ecosystems. One of the primary difficulties in assessing STP success is the absence of a universal set of indicators that can be uniformly applied across different parks (Westhead, 1997). STPs vary significantly in terms of size, focus areas, and objectives (Chan and Lau, 2005), making it challenging to develop a standardised measurement framework that effectively captures the unique characteristics and goals of each park (Germain et al., 2022). Furthermore, the operation of STPs within complex ecosystems adds another layer of complexity to the measurement process (Carayannis et al., 2018). STPs are influenced by various external factors including the regional economy, policy frameworks, cultural aspects, and industry dynamics (Poonjan et al., 2022; Latorre et al., 2017). These external influences can significantly impact the performance and success of STPs, making it challenging to isolate the effects of internal strategies and initiatives on overall outcomes. Moreover, the dynamic nature of technology and innovation further complicates the measurement of success in STPs. Rapid advancements in technology, changes in market demands, and evolving industry trends require STPs to continuously adapt and innovate to remain relevant and competitive (Vásquez-Urriago et al., 2014).

Recent studies have focused on identifying key indicators and metrics for assessing the success of STPs. Tofighi et al. (2017) emphasised the significance of effective communication with universities and research institutions for health research centres, highlighting the importance of academic collaboration in achieving STP success. Ünlü et al. (2023) stressed the need to evaluate university science parks based on a diverse range of indicators, including economic and innovative performance, firm-public research organisation relationships, and knowledge spillovers. This underscores the importance of considering the economic and innovation outcomes when assessing a park's success. Ng et al. (2020) explored the perceived benefits of science park features among tenants and highlighted the significance of park facilities and services in providing tangible benefits to firms. The study emphasised that infrastructure quality and support services are essential for STP success. Furthermore, Albahari et al. (2017) noted considerable variability in university engagement within STPs, suggesting that the level of university involvement can have a significant impact on park success.

Additionally, Weng et al. (2019) scrutinised the critical success factors for private science parks established through brownfield regeneration, stressing the significance of factors such as industry collaboration, environmental restoration, and private sector involvement in the development of science parks. This study indicated that a multi-stakeholder approach and sustainable development practices are vital considerations in evaluating the success of STPs. Furthermore, Hemati and Mardani (2012) proposed a performance appraisal system based on a balanced scorecard to enhance productivity in science and technology parks. This approach emphasises the importance of a comprehensive and balanced evaluation of the success of these parks, taking into account various dimensions, including financial, customer, internal processes, learning and growth. Additionally, critical success factors in STPs, such as the innovativeness of technology-based firms, knowledge management, and leadership competency models, are essential for achieving success (Lee and Kim, 2018; Westhead, 1997; Kazemi and Allahyari, 2010). It is also essential to understand the drivers of patent performance, regional contextual factors, and antecedents of innovation in evaluating the success of STPs (Ünlü et al., 2023; Poonjan and Tanner, 2020; Murat and Baki, 2011).

In summary, the effectiveness of Science and Technology Parks (STPs) depends on several factors, including collaboration with universities, the use of diverse evaluation metrics, and the provision of high-quality facilities and services. The involvement of universities, industry collaboration, and environmental sustainability are key elements. However, STPs also face challenges, such as the diversity of park characteristics and the rapidly changing nature of technology. A well-balanced performance appraisal system is necessary to ensure success in STPs.

2.6.2 Literature on success factors in innovation parks

The academic literature on success factors in Science and Technology Parks (STPs) encompasses a vast array of studies that delve into the critical elements influencing the performance and effectiveness of these innovation ecosystems. Numerous key themes emerged from the research conducted in this field, including the creation of value for tenants (Martínez-Cañas et al., 2012), the role of research and development (R&D) inputs and outputs (Albahari et al., 2018), critical success factors for business incubators within STPs (Corsaro et al., 2012), and the functions of university science and technology parks (Montoro-Sánchez et al., 2011). Furthermore, research has explored the value-added contributions of STPs to new technology-based firms (Albahari et al., 2018), the perceived benefits of science park attributes among tenants (Murat and Baki, 2011), and the management of STPs in different regions (Vásquez-Urriago et al., 2014).

In a study conducted by Poonjan and Tanner (2020), the authors highlighted the critical role of regional contextual factors in the success of science and technology parks. They emphasised the necessity of considering these factors to improve the operational efficiency of STPs. Additionally, Entringer and Silva (2020) conducted a comprehensive literature review to identify critical success factors for STPs. Their study aimed to categorise and evaluate the essential variables that contribute to the growth of STPs. By synthesising information from various sources, Entringer and Silva (2020) contributed to a better understanding of the factors that contribute to the effectiveness and sustainability of STPs. Furthermore, Albahari et al. (2023) established a critical success factor framework for Science and Technology Parks (STPs) and utilised it to analyse specific STPs, such as BIORIO in Brazil and the Virginia Tech Corporate Research Center in the United States. This study examines a range of aspects vital for the efficient functioning and performance of STPs, providing valuable insights for policymakers, managers, and researchers in the field. Additionally, Hu and Lin (2013) emphasised the effectiveness of STPs in integrating industry and regional development, citing the example of the Hsinchu Technopolis in Taiwan. This case study illustrated how STPs can serve as effective instruments for promoting collaboration between industries and regional development.

In addition, Martínez-Cañas et al. (2021) explored the role of knowledge in science and technology parks, emphasising their function as public-private partnerships designed to enhance regional wealth and promote technology start-ups. This underscores the vital knowledge-sharing aspect within STPs, which is essential for their success. Furthermore, Lee and Kim (2018) proposed a leadership competency model for STPs based on the case of Chungbuk Techno Park in Korea, highlighting the economic benefits that STPs bring to regions. This model highlights the importance of effective leadership in driving the success of STPs. Moreover, Vásquez-Urriago et al. (2014) significantly enhanced the discourse by emphasising the importance of strategic planning, competent management, supportive political environments, collaboration, knowledge-sharing, and science popularisation for the efficient operation of STPs.

The IASP Survey (2022) identified the key factors contributing to the success of respondents' AOIs/STPs, as shown in table 2.3. The most critical elements are talented, motivated individuals in resident companies, and the AOI/STP's image and prestige, with 64.6% and 67.3% of respondents rating these as "very important”, respectively. Notably, location consistently ranked among the top five factors in earlier surveys. In 2018, 61.5% of respondents deemed location "very important”, but this decreased to 45.1% in the latest survey, likely due to the COVID-19 pandemic (IASP Survey, 2022).

Table 2.3: Factors contributing to the success of the AOIs/STPs. Source, IASP Survey (2022)

	Not important	Slightly important	Moderately important	Very important
AOI/STP’s image/prestige	0.9%	6.2%	24.8%	67.3%
Talented and motivated people working in tenant companies	0.9%	8.8%	25.7%	64.6%
Links to university/HEI	1.8%	8%	28.3%	61.9%
A growing number of successful mature companies	0.9%	8.8%	28.3%	61.9%
A growing number of successful start-ups	0.9%	7.1%	31%	61.1%
Presence of ‘anchor’ companies	0.9%	15.9%	31%	52.2%
Increased co-creation and open innovation processes amongst companies onsite or local	1.8%	13.3%	32.7%	52.2%
Institutional presence/support	1.8%	13.3%	37.2%	47.8%
Increased collaboration between AOI/STP companies and the local university	2.7%	5.3%	44.2%	47.8%
Successful technology/knowledge transfer process	1.8%	15%	36.3%	46.9%
Increase in innovation activities	3.5%	11.5%	38.1%	46.9%
Success in obtaining funding for R&D projects	4.4%	12.4%	37.2%	46%
Location	2.7%	15.9%	36.3%	45.1%
Access to markets	1.8%	16.8%	35.4%	45.1%
Growth in the number of employees in the resident companies	2.7%	15%	38.9%	43.4%
Increased international connections and opportunities for resident companies	3.5%	8.8%	45.1%	42.5%
Local demand/customers	2.7%	30.1%	27.4%	39.8%
Collaboration with city programmes/activities	4.4%	22.1%	34.5%	38.9%
Increased collaboration between AOI/STP and the city/ surrounding community	0.9%	20.4%	42.5%	36.3%
International relations	2.7%	24.8%	44.2%	28.3%

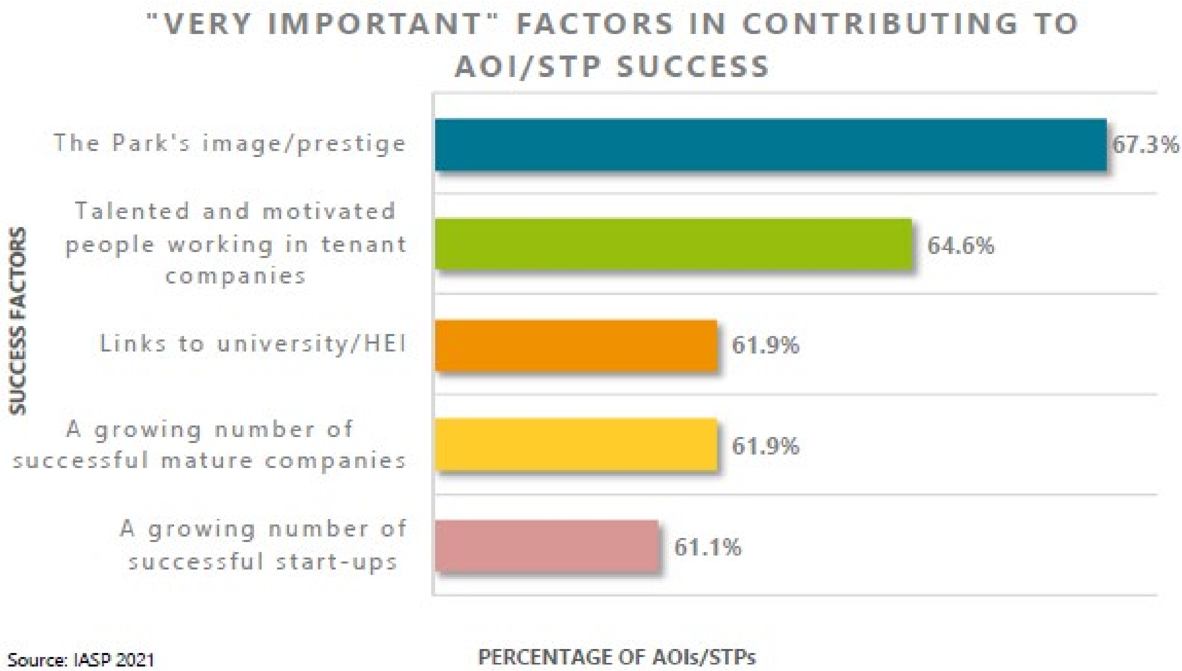


Figure 2.9: 'Very Important' Success Factors in Contributing to the Success of AOIs/STPs (IASP Survey, 2022)

2.7 Models and Frameworks for Assessing STP Success

2.7.1 Overview of existing models and frameworks

Evaluating the effectiveness of science and technology parks (STPs) requires tailored methodologies that consider regional dynamics, intellectual capital, leadership, and stakeholder engagement to optimise performance and societal impact. Fojs and Detelj (2021) present a model for assessing the intellectual capital of technology parks, providing a valuable tool for measuring the success of STPs. Additionally, it is imperative for the success of science and technology parks to have effective leadership, as highlighted by Lee and Kim (2018) and further emphasised by Cadorin et al. (2019). These sources stress the significance of a leadership competency model tailored for STPs to drive their success. Furthermore, Makhdoom et al. (2022) highlight the vital role of universities and academic research, indicating the necessity of strong connections between universities, research institutes, and firms to stimulate innovation and entrepreneurship within the science park model.

Davoudi et al. (2018) present a sophisticated comprehension of the intricate relationships between intellectual property rights, open innovation, and the performance of small and medium-sized enterprises (SMEs) in the technology and innovation management field. Their study emphasises the necessity of a comprehensive approach to evaluate the interplay of multiple factors in fostering success in these innovation ecosystems.

However, the existing models for assessing the success of STPs face notable critiques and limitations. A major criticism identified in the literature is the absence of a systematic understanding of the impact of regional contextual factors on the performance of STPs (Poonjan and Tanner, 2020). This indicates a gap in the current models that fails to adequately consider the broader regional environment in which STPs operate. In addition, the high number of criteria involved in evaluating STPs poses a challenge, requiring a system capable of effectively comparing numerous science parks (Nosratabadi et al., 2011).

Makhdoom et al. (2022) emphasise the importance of considering all essential components for achieving STPs' objectives, highlighting the need for a more comprehensive approach encompassing factors such as the integration of autonomous systems, value creation, emerging technologies, security and privacy considerations, and data services. Another limitation of prevailing STP models is their narrow focus on technology transfer and commercialisation, which overlooks other critical aspects of innovation, such as creativity and incubation. Díez-Vial and Fernández-Olmos (2015) explored the concept of knowledge spillovers within STPs and how firms can leverage them. However, this narrow focus on knowledge transfer disregards the importance of creativity and incubation in the innovation processes. Fatta et al. (2018) highlight the role of technology in aiding decision-makers in addressing innovation challenges, underscoring the need for a more inclusive STP model that not only concentrates on technology transfer but also on fostering creativity and supporting incubation processes.

Furthermore, Narasimhalu (2015) examined the existing models of collaboration between universities, businesses, science parks, and research institutions. This source emphasises the importance of constructing robust connections between science parks and universities to facilitate co-operation and knowledge sharing. With regard to evaluation models, the necessity of adopting a balanced approach between 'exogenous' and 'endogenous' innovation strategies in diverse regional contexts is emphasised (Etzkowitz and Zhou, 2018). This indicates that prevailing models might not adequately consider the diverse impacts and growth factors impacting Science and Technology Parks (STPs), potentially restricting their applicability across various settings. In terms of specific success factors for science parks, one study has identified essential elements such as resource-sharing capacity, park scale, financing services, legal policies, and construction level of facilities as critical for success (Weng et al., 2019). This highlights the importance of customising assessment models to account for the unique characteristics and requirements of the different types of STPs.

In summary, while current models for evaluating Science and Technology Parks (STPs) offer valuable insights, they often overlook the complexity of these innovation ecosystems. The literature highlights the need for a more comprehensive approach that considers regional conditions, intellectual capital, leadership, and strong university-industry links. Addressing the limitations of existing models, such as their narrow focus on technology transfer and insufficient attention to regional factors, can enhance the effectiveness of STPs. A more holistic evaluation framework would better support the development and sustainability of these vital innovation hubs.

2.7.2 Adaptation and customization of models for STPs

To effectively assess the success of Science and Technology Parks (STPs), it is essential to consider the adaptation and customisation of models tailored to the specific context and needs of these parks. Sanni et al. (2010) suggested a model designed to aid policymakers and managers in implementing and managing science and technology parks in developing countries. This underscores the importance of adopting a structured approach in the STP design and operation. Different models of organisation and ways of co-operation can be adopted in the development of science and technology parks, depending on the specific industry and context (Staszków et al., 2017). Additionally, the governance structure and collaboration between higher education institutions (HEIs) and science and technology parks are essential considerations in the adaptation and customisation of models (Kang, 2016). Effective governance structures are necessary for facilitating co-operation and knowledge exchange between HEIs and science and technology parks (Kang, 2016). These structures ensure that the expertise and resources of HEIs are effectively utilised in the innovation process.

Moreover, Weng et al. (2019) proposed a technology selection model for science parks that emphasises the importance of evaluating the technology level and assimilation rate when making decisions regarding technology selection within these innovation hubs. The model developed by Weng et al. (2019) provides valuable insights into how technology transfer collaborations between science parks and universities can be effectively supported, highlighting the significance of strategic technology management within STPs and the need for a systematic approach to managing technology resources and promoting innovation within these ecosystems. Furthermore, Correia et al. (2021) stressed the necessity of developing customised information systems that align operational processes with the distinct characteristics of science and technology parks to improve their success.

In summary, the development of a customised model that caters to the unique circumstances and requirements of STPs is of paramount importance. To achieve this, a thoughtful blending of business processes and selection of appropriate technologies is necessary. Moreover, recognising critical success factors is essential for enhancing STP efficiency and promoting innovation and economic advancement. Additionally, robust governance structures, collaborations with higher education institutions, and the implementation of specialised information systems are indispensable for optimising STP performance and realising their full potential.

2.8 STPs in Regional Growth and Innovation

2.8.1 Enhancing regional growth through science and technology parks

Science and technology parks are renowned for their ability to create economic clusters centred on technology and research, which in turn enhances regional competitiveness (Sudiana and Hendayani, 2020). STPs are considered essential for promoting regional economic growth and international competitiveness, not only in developed countries but also in emerging nations (Lam et al., 2021). As hubs that bring together various disciplines, they act as incubators for new ideas, technologies, and businesses, thereby contributing to the economic development of regions and countries (Veljković and Stankovic 2018). They are regarded as catalysts for economic and industrial advancement in developing countries (Gursel, 2014). However, it is essential to recognise that science and technology parks cannot solely promote high-technology-led economic development at the regional or national level. Instead, they should be considered as integral components of a well-considered and coordinated development strategy that maximises regional or national strength (Amirahmadi and Saff, 1993).

Research conducted by Feng et al. (2021) underscores the considerable influence of STPs on the development and expansion of technology-based businesses, the generation of new start-ups, and the creation of employment opportunities. These parks serve as vital hubs for high-tech industries, represent advanced productive forces, and make a significant contribution to regional economic prosperity, as emphasised by Zhang et al. (2021). Furthermore, STPs play a pivotal role in promoting regional innovation and economic development, leading to the creation of new jobs and specialised labour opportunities (Entringer and Silva, 2020) and promoting social and economic empowerment (Esponilla et al., 2019). Moreover, science and technology parks are essential components of research and development ecosystems designed to enhance university-industry collaboration and foster a knowledge-based economy (Arslan and Belgin, 2020). The establishment of STPs is an integral part of national development strategies, reflecting their importance in driving economic growth and technological advancement (Khanmirzaee et al., 2018).

In summary, Science and Technology Parks (STPs) are pivotal for technology-driven businesses and regional growth. Their impact is maximised when they are integrated into coordinated development strategies that leverage regional strengths. STPs are instrumental in fostering collaboration between universities and industries, which is essential for driving economic growth and promoting the knowledge economy at both the national and regional levels.

2.8.2 Science parks as catalysts for high-tech start-up growth and innovation

The establishment of science parks has accelerated the transfer and transformation of scientific and technological achievements, effectively promoting the growth and development of regional high-tech industries (Yan et al., 2020). Moreover, science parks are designed to harness the collective energy of participating groups, increasing the likelihood of innovation and contributing to economic growth through the development of high-tech firms (Bannon and Byrne, 1997).

STPs function as intermediaries, creating a platform for co-operation and networking between academia and industry, thereby fostering an ecosystem where researchers and entrepreneurs can interact, exchange ideas, and form partnerships to develop and commercialise innovative technologies (Spithoven, 2015; Díez-Vial and Fernández-Olmos, 2015). Through this collaboration, STPs bridge the gap between theoretical knowledge and practical applications, resulting in the creation of marketable products and services.

Additionally, STPs often offer support services, such as incubation programs, business development assistance, and access to funding, which help start-ups and small businesses transform their innovative ideas into marketable products or services (Alishiri et al., 2018; Kang, 2016). These parks act as a platform for collaboration between universities, research institutions, and industry, facilitating the exchange of knowledge and commercialisation of scientific and technological advancements (Westhead, 1997; Oliver et al., 2020; Sanyal and Hisam, 2018). A vital aspect of supporting start-ups and small and medium-sized enterprises in science and technology parks is furnishing them with information, guidance, and services that promote their growth and development (Khayatian, 2021). Additionally, STPs offer a resource network that connects technology-based businesses with significant stakeholders such as investors, mentors, and potential partners (Westhead, 1997). This network enhances the growth prospects of start-ups and SMEs by providing them with valuable connections and opportunities for collaboration (Westhead, 1997).

Furthermore, science and technology parks play a significant role in providing support to start-ups and small and medium-sized enterprises (SMEs) in their initial stages by facilitating positive interactions among various stakeholders, as highlighted by Sudiana et al. (2020). In addition, science and technology parks not only provide physical infrastructure and networking opportunities, but also support the growth of start-ups and small and medium enterprises by offering financial aid and access to funding resources (Ke et al., 2011). STPs can facilitate the flow of capital and investment into start-ups and SMEs by establishing effective mechanisms that bring together government agencies, SMEs, banks, and guarantee agencies (Ke et al., 2011).

The bar chart below (figure 2.10) illustrates the distribution of startups that are less than three years old across Areas of Innovation (AOIs) and Science and Technology Parks (STPs) based on the percentage of such startups in each area. The majority of AOIs/STPs (32%) have 11-25% of their startups less than three years old, indicating a moderate level of early stage entrepreneurial activity. Furthermore, 21.6% of AOIs/STPs have a small proportion (1-10%) of young startups, whereas 17.5% have none. However, only a small fraction of AOIs/STPs have a high concentration of young startups, with only 6.2% having more than 70% of their startups that are less than three years old.

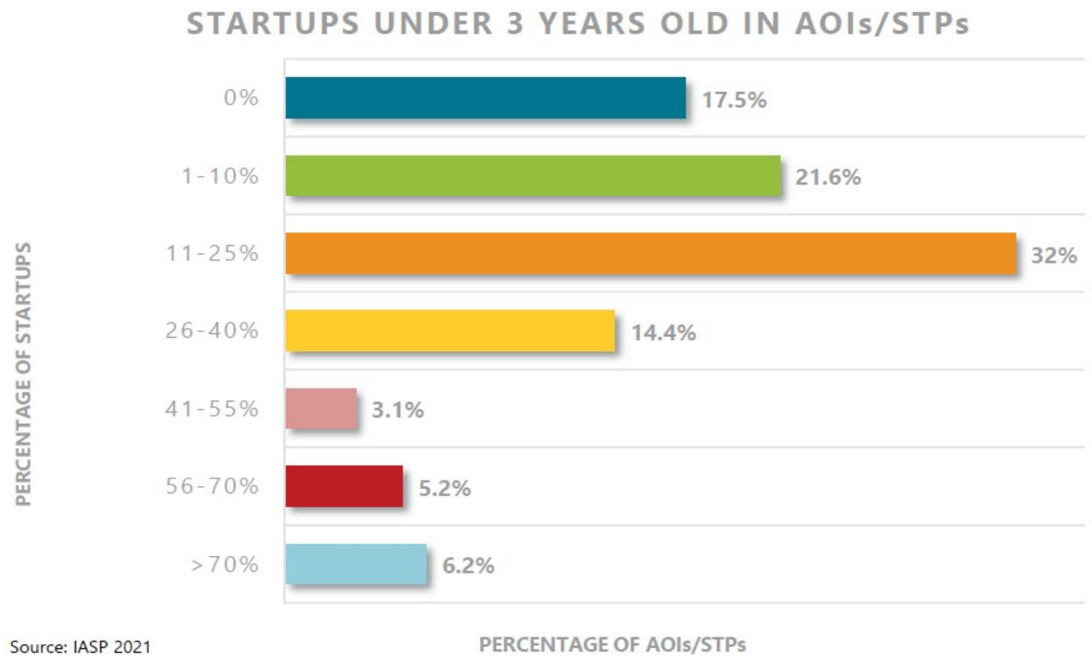


Figure 2.10: Distribution of Young Start-ups Under 3 Years Old in AOIs/STPs: Percentage Breakdown (IASP Survey, 2022)

2.8.3 Fostering innovation through incubation and acceleration in STPs

Incubation and acceleration programs are commonly found in science and technology parks, which serve as physical spaces where start-ups, research institutions, and industry players come together to foster innovation and collaboration (Cuvero et al., 2023). Science and technology parks often house incubators and accelerators, providing start-ups with a supportive ecosystem and access to a wide range of resources (Woolley and MacGregor, 2022). They provide a platform for start-ups to connect with potential partners, investors, and customers, thereby enhancing their chances of success (Cuvero et al., 2023).

Incubators frequently operate within science and technology parks, which function as hubs for innovation and collaboration (Gursel, 2014). They offer a variety of services including office space, access to funding, business development support, and networking opportunities (Lose and Tengeh, 2016). Incubation programs are renowned for their continuous nature, allowing start-ups to benefit from ongoing support and guidance (Cohen, 2013). They are particularly advantageous for start-ups that require an extended period to develop their products or services and to establish a solid foundation for growth (Yu et al., 2009).

However, unlike incubators, accelerator programs are typically shorter in duration, ranging from a few months to one year (Uhm et al., 2018). Accelerators often adopt a cohort-based model in which a group of start-ups progresses through an intensive program (Butz and Mrożewski, 2021). The primary objective of accelerator programs is to provide start-ups with the necessary resources, mentorship, and connections to accelerate their growth and achieve milestones within a short period (Cohen, 2013). Accelerators typically have a competitive selection process, ensuring that only high-potential start-ups with proven market fit are accepted into the program (Uhm et al., 2018). They also provide access to a network of investors and industry experts, thereby increasing the likelihood of securing funding and partnerships (Butz and Mrożewski, 2021).

In summary, science and technology parks are essential for promoting innovation through incubation and acceleration. These parks provide vital resources, financial support, and networking opportunities that aid the growth of start-ups. Incubators offer long-term support to help start-ups establish a solid foundation, whereas accelerators provide intensive, short-term assistance to hasten progress and achieve key milestones. Collectively, these programs effectively bridge the gap between initial development and market preparation, driving entrepreneurial success and technological progress.

2.9 Governmental Investment and the Global Impact of Science Parks on Innovation and Growth

2.9.1 Government investment in science sarks as catalyst for innovation and growth

Governments often invest in establishing science parks to create an environment that is conducive to innovation and entrepreneurship. This is achieved by providing funding for the construction of research facilities, laboratories, and incubation centres, as well as the development of necessary infrastructure such as roads, utilities, and communication networks (Akgün and Güner, 2022; Zhang and Sonobe, 2010; Phillips and Yeung, 2003). Policies and regulations have been formulated to encourage collaboration among academia, industry, and government, and incentives have been provided for technology transfer, intellectual property protection, and investment in research and development (Akgün and Güner, 2022; Wu et al., 2015; Yan and Chien, 2013; Kang, 2016). Governments also work with universities and research institutions to ensure a steady supply of skilled professionals and researchers to support the activities of science and technology parks (Cadorin et al., 2019; Wu et al., 2015; Alishiri et al., 2018). In addition, partnerships are established with industry associations and business organisations to foster innovation and technology transfer (Fukugawa, 2006; Guo and Verdini, 2015; Gursel, 2014; Koh et al., 2005). Furthermore, the government provides support for marketing activities such as trade shows, exhibitions, and business matchmaking events. These events aim to connect science and technology parks with potential investors and industry partners (Guo and Verdini, 2015; Phillips and Yeung, 2003; Robani, 2015).

According to the findings of the IASP Survey (2022), the most significant proportion of areas or parks surveyed (41.6%) are situated on land owned by government bodies, and the government is considered the most valuable, with 69% of respondents indicating that it is "very important".

Figure 2.11 shows a visual representation of the financial aid provided by the government to the AOIs/STPs. A substantial portion of the areas/parks (58.1%) allocated the majority of their funding towards human resources and property development (47.3%), while a minority of institutions directed their funding towards property purchases (20.3%) and capital acquisition (24.3%) (IASP Survey, 2022).

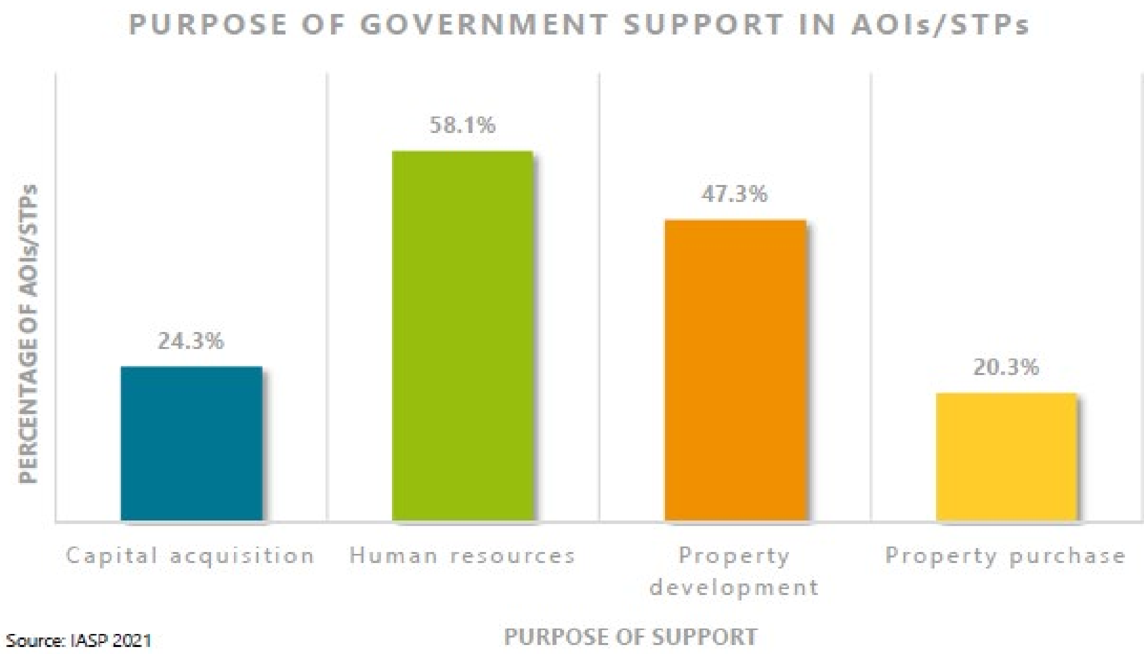


Figure 2.11: Purpose of Government Support in AOIs/STPs (IASP Survey, 2022)

In summary, the role of governmental investment is of paramount importance in achieving success in science and technology parks. This investment provides vital infrastructure, finance, and policy support necessary for fostering innovation; facilitating collaboration between academia, industry, and government; and ensuring a skilled workforce. The utilisation of public land and the prioritisation of resources towards human capital and infrastructure serves to emphasise the government's indispensable role in driving technological progress and economic growth.

2.9.2 Science parks and global technological advancement

A comparative analysis of Science and Technology Parks (STPs) worldwide reveals a complex landscape of innovation centres that play an indispensable role in nurturing technology-based businesses and connecting scientific research to commercial production (Westhead, 1997). These parks, often placed near universities, serve as vital networks for technology-driven companies, providing them with vital resources and facilitating inter-organisational knowledge sharing, which is critical for driving innovation within these ecosystems (Balle et al., 2019). The primary objective of establishing science parks is to act as a catalyst for industrial revitalisation and development by creating an environment that fosters the transformation of pure research into tangible products and processes (Löfsten and Lindelöf, 2002). Examining the development, evolution, and sustainability of science parks and related regional phenomena is essential to understanding their impact and effectiveness (Koh et al., 2005). The success of science and technology parks, such as the renowned Stanford Science and Technology Park, has led to their global proliferation, with countries and regions aiming to enhance their innovation capacity by establishing similar hubs (Walcott, 2002).

In recent years, Science and Technology Parks (STPs) have come to be widely acknowledged as essential tools for implementing innovation policies at both the European Union and national levels (Staszków et al., 2017). These parks are known for their role in facilitating the integration of technology, industry incubation, and technology demonstration, thereby contributing to the advancement of various sectors including agriculture, medicine, and high-tech industries (Li et al., 2023; Yang et al., 2018). The development of national Science and Technology Parks, particularly in countries such as China, has been a strategic focus for driving economic growth and technological advancement (Zhang and Sonobe, 2011; Yang et al., 2018). Establishing Science Parks is often part of a broader strategy to create new engines of growth and enhance regional competitiveness by fostering innovation and knowledge-based industries (Yan and Chien, 2013; Yang et al., 2018).

Bakouros et al. (2002) evaluated the performance and outcomes of Science Parks in Greece to assess their impact on the high-tech industry. This study offers a localised perspective on the challenges and opportunities within these innovation ecosystems, providing a nuanced understanding of the factors influencing the success or shortcomings of Science Parks in Greece. This study is valuable to policymakers and stakeholders involved in innovation and technology transfer. Bigliardi et al. (2006) conducted a case study on Italian Science Parks to evaluate their performance and impact on innovation and economic development in the country. By focusing on specific case studies, this study sheds light on the unique characteristics and challenges faced by Science Parks in Italy and provides insights into their operational dynamics. Phillimore (1999) evaluated innovation in science parks, specifically analysing the Western Australian Technology Park, while Chen and Huang (2004) conducted a multiple-criteria evaluation of high-tech industries in Taiwan's science-based industrial parks, emphasising the importance of such parks in driving technological advancements.

According to a report by UN.ESCAP (2019), there were 534 science and technology parks (STPs) worldwide as of 2017, of which 169 were located in Asia and the Pacific Ocean. The majority of these STPs are found in advanced or large economies. Developing economies are increasingly using STPs as part of their national strategies to bridge this technological gap. UNCTAD (2018) reported that approximately 80% of the countries surveyed, including both developed and developing nations, planned to incorporate specialised zones, such as STPs, into their twenty-first-century industrial policies.

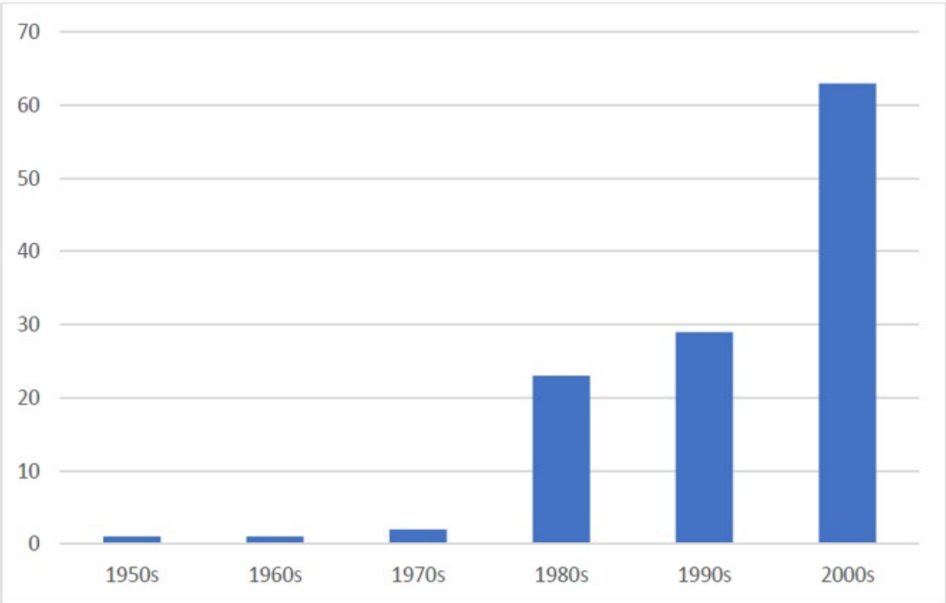


Figure 2.12: The Number of STPs Launched in Each Decade, Source: IASP Survey 2012

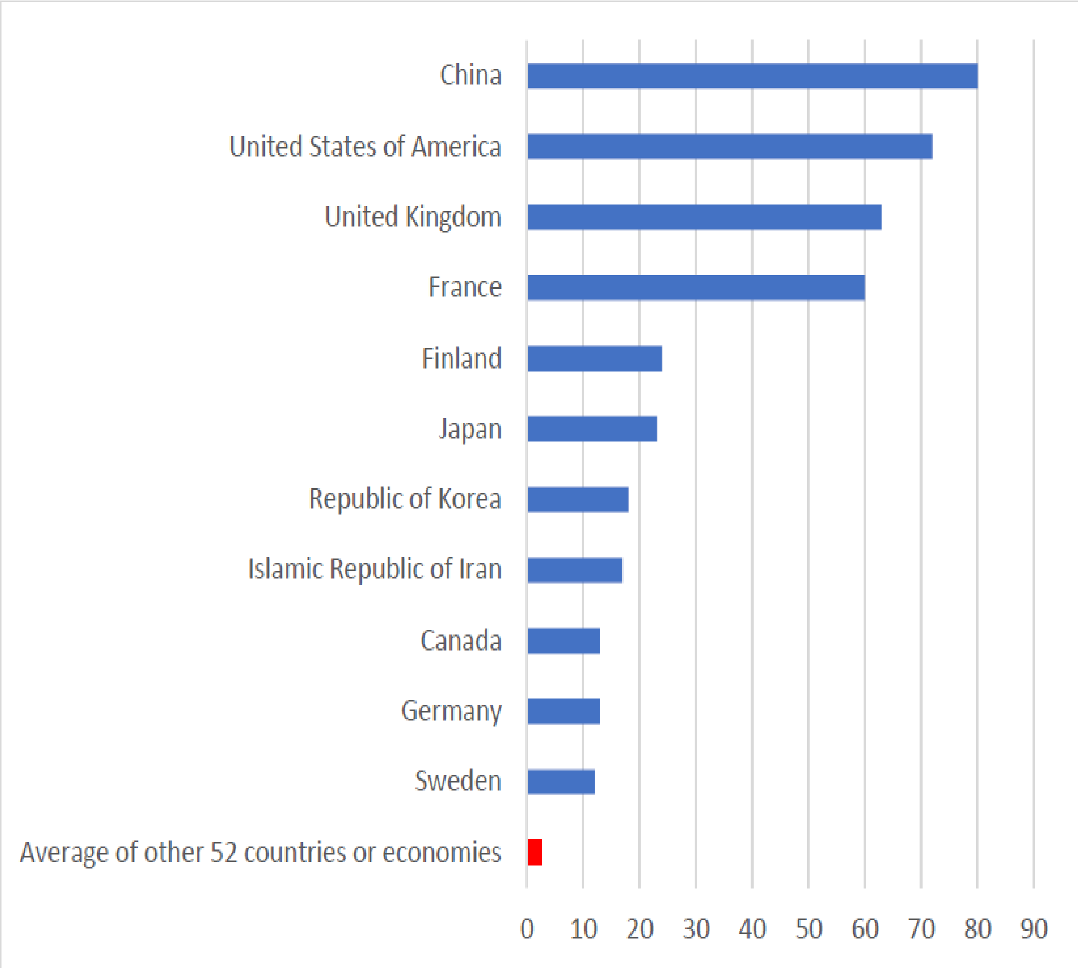


Figure 2.13: The Number of STPs by Country or Economy, 2017, Source: UN.ESCAP (2019)

In summary, the global proliferation of STPs reflects their success in enhancing regional competitiveness and in supporting technology-based industries. As both developed and developing countries integrate STPs into their industrial strategies, understanding their diverse impacts and challenges remains essential for optimising their effectiveness in advancing technological innovation and economic development.

2.10 Challenges and Unexplored Dimensions of Science Parks

2.10.1 Challenges in science and technology parks

Science and Technology Parks (STPs) have been established as valuable mechanisms for promoting innovation and fostering economic development in many nations (Staszków et al., 2017). Nevertheless, despite their potential, these parks frequently face a range of obstacles that can hinder their efficiency. This section explores some of the challenges faced by STPs and the consequences that follow.

One of the challenges faced by STPs is the need for effective collaboration and co-operation among various stakeholders, including universities, research institutions, and industries (Tofighi et al., 2017). The success of STPs depends on their ability to establish strong partnerships and facilitate knowledge exchange between these entities (Staszków et al., 2017). However, achieving effective collaboration can be difficult because of differences in organisational culture, goals, and priorities (Etzkowitz and Zhou, 2018). This challenge emphasises the importance of creating mechanisms and platforms for communication and collaboration between stakeholders (Tofighi et al., 2017). Another challenge STPs face is the need for adequate financing and financial stability (Henriques et al., 2018). STPs require substantial investment in infrastructure, facilities, and support services to lure and retain innovative companies. However, acquiring funding can be difficult, particularly in regions with limited financial resources (Gower and Harris, 1994). Furthermore, STPs need to establish sustainable business models to generate revenue and cover operational expenses (Hansson, 2007). This challenge highlights the importance of formulating effective financing strategies and exploring diverse revenue streams, such as partnerships with private investors and government support (Henriques et al., 2018).

Furthermore, STPs face significant challenges in attracting and retaining highly skilled and qualified workers (Weng et al., 2019). To overcome this challenge, STPs need to implement effective strategies to attract and retain talent, such as offering competitive salaries, providing opportunities for professional development, and promoting a supportive and collaborative work environment (Weng et al., 2019).

Additionally, science and technology parks face the challenge of ensuring effective technology transfer and commercialisation of research outcomes (Link and Scott, 2017). The primary aim of STPs is to facilitate the transfer of knowledge and technology from universities and research institutions to industries. However, this process can be intricate and requires effective mechanisms for intellectual property protection, licencing agreements, and technology commercialisation. To address this challenge, STPs need to establish robust linkages between academia and industry, provide support services for technology transfer, and facilitate the creation of spin-off companies (Link and Scott, 2017).

Moreover, STPs face difficulties adapting to fluctuating market dynamics and technological advancements. The success of STPs depends on their capacity to remain ahead in the field of technological innovation and address changing market needs. However, rapid advancements in technology and market disruptions can pose challenges to STPs in terms of maintaining their relevance and competitiveness (Zhu et al., 2023). To remain relevant, STPs must continuously update their strategies, infrastructure, and support services to align with the market demands and emerging technologies.

According to the IASP Survey (2022), a significant number of respondents reported facing significant barriers to the ongoing development of Areas of Innovation/Science and Technology Parks (AOIs/STPs) despite a generally positive outlook. Specifically, 41.6% of respondents identified a lack of financial resources as a “very constraining” factor, while 36.3% cited a lack of public sector support. Meanwhile, 58.4% of organisations did not view low real estate income as a "moderately" or "very" constraining factor, but 20.4% indicated that their success in attracting foreign investment was constraining. Additionally, 19.5% of the respondents reported that a lack of collaboration with universities was a "very constraining" factor.

Table 2.4: Factors Considered Constraints on the Ongoing Development of AOIs/STPs, Source: IASP Survey Report, 2022

	Not Constraining	Slightly Constraining	Moderately Constraining	Very Constraining
Lack of financial resources (including access to finance)	11.5%	15%	31.9%	41.6%
Lack of public sector support	14.2%	26.5%	23%	36.3%
Government (federal/regional/local)	10.6%	30.1%	30.1%	29.2%
Little to no success in attracting foreign investment	23.9%	30.1%	25.7%	20.4%
Lack of collaboration with universities/HEIs	14.2%	31.9%	34.5%	19.5%
Lack of trade and industry support	15%	31.9%	37.2%	15.9%

Lack of institutional support	16.8%	29.2%	38.1%	15.9%
Low real estate income	26.5%	31.9%	26.5%	15%
Slow growth of resident companies	15.9%	27.4%	46%	10.6%

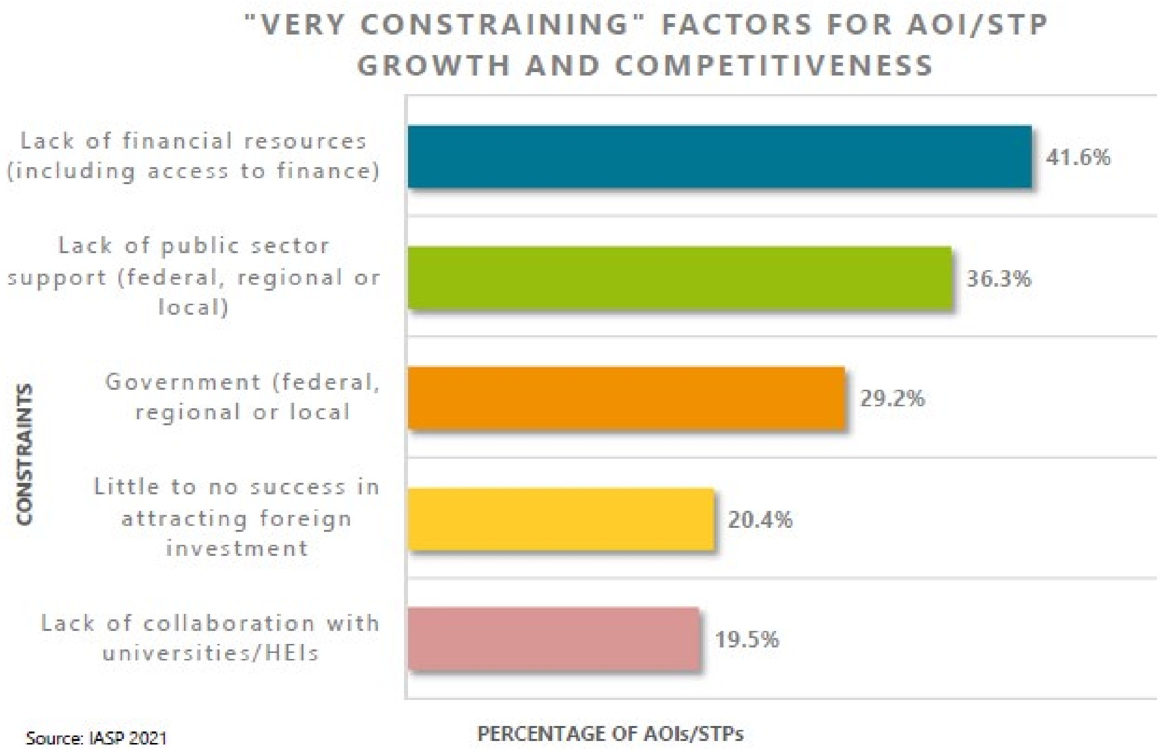


Figure 2.14: 'Very Constraining' Factors for AOIs/STPs Growth (IASP Survey, 2022)

In summary, Science and Technology Parks (STPs) play an indispensable role in driving innovation and economic development. However, these parks face several obstacles, which may impede their efficiency. These challenges include promoting effective collaboration among various stakeholders, acquiring ample funding, retaining skilled personnel, and ensuring successful technology transfer and commercialisation. Moreover, STPs must consistently adapt to changing market conditions and technological advancements to preserve their relevance. Overcoming these challenges is imperative for STPs to realise their potential as engines of innovation and growth in the global economy, as highlighted by

Löfsten et al. (2020), González-Masip et al. (2019), Cadorin et al. (2017), and Cadorin et al. (2019).

2.10.2 Unexplored aspects of science and technology parks

Science and Technology Parks (STPs) have been extensively researched and debated among academics, practitioners, and policymakers because of their role as instruments for innovation policies (Albahari et al., 2018). Although previous studies have highlighted the positive impact of STPs on firms, there are still unexplored areas within this domain, particularly how STPs create value for tenants (Albahari et al., 2018). One important aspect that remains unexplored is the influence of regional contextual factors on STP performance (Poonjan and Tanner, 2020). Understanding how these external elements affect the functioning and outcomes of STPs is essential for optimising their effectiveness. Moreover, the dynamics of inter-organisational knowledge spillovers within STPs and their role in attracting talent and fostering corporate social responsibility practices represent another area of research (González-Masip et al., 2019). Investigating the mechanisms through which knowledge flows within and outside STPs can provide valuable insights for enhancing innovation networks and collaboration. Additionally, exploring the sustainability performance of firms within STPs and the factors that influence it, such as knowledge sources and absorptive capacity, presents a promising avenue for further investigation (Forés and Fernández-Yáñez, 2023).

Moreover, it is essential to examine more deeply the role of Science and Technology Parks (STPs) in the development of a knowledge-based economy (Khanmirzaee et al., 2018). Exploring how STPs contribute to the growth of economies driven by knowledge and innovation can provide valuable guidance for policymakers and stakeholders. Additionally, investigating the specific support that start-ups require from STPs can shed light on how these innovation hubs can facilitate the success of new ventures (Lee et al., 2021). The design and development of STPs in developing countries represent a vital area that requires more attention (Sanni et al., 2010). Developing a model tailored to the unique challenges and opportunities in these regions can significantly affect the effectiveness of STPs in fostering innovation and economic growth. Furthermore, evaluating the organisational architecture of STPs under varying innovation environments can provide valuable insights into optimising their structures for enhanced performance (Al-Kfairy et al., 2020).

The relationship between Science and Technology Parks (STPs) and universities, as well as their role as intermediaries for green innovation, presents fascinating opportunities for further investigation (Hermann et al., 2020). It is essential to explore how STPs can successfully bridge the gap between academia and industry to achieve sustainable innovation outcomes. Moreover, examining the efficiency of STPs using methods such as Data Envelopment Analysis can offer invaluable insights into their operational effectiveness and impact (Arslan and Belgin, 2020). Furthermore, studying the impact of STPs on regional economic development, performance management practices within STPs, and the satisfaction of tenants in these parks are areas that require further exploration (Sudiana and Hendayani, 2020; Staszków, 2016). By delving into these aspects, researchers can gain a comprehensive understanding of the multifaceted roles of STPs and identify strategies to optimise their contributions to innovation ecosystems.

In summary, Science and Technology Parks (STPs) are of great importance in stimulating innovation and boosting economic progress. However, their full potential is yet to be realised. It is essential to concentrate on the influence of regional contextual factors, mechanics of knowledge spillovers, and the particular requirements of start-ups within these parks in future research. Examining the role of STPs in developing economies and their contribution to a knowledge-based economy can provide valuable insights into enhancing their efficacy, enabling researchers and policymakers to optimise STPs as catalysts for innovation and sustainable growth (Löfsten and Lindelöf, 2002).

Table 2.5: Literature Review Synthesis

Section	Theme	Key Findings	Gaps/Challenges	Key Authors/Studies
2.2 Evaluation of STPs	Evolution and Role of STPs	STPs have evolved since the 1950s, inspired by models like Silicon Valley, to foster university-industry collaboration and drive regional innovation.	Sustainability and resource allocation challenges, need for adaptation in resource-limited areas, and growing regional inequalities due to concentrated innovation hubs.	Klepper (2010); Mansour & Kanso (2018); Tataj et al. (2022); Khan (2018)
2.2.1 Historical Overview	Global Development Trajectory	Global expansion marked by diverse STP models; STPs seen as critical to innovation and knowledge economies.	Limitations in replicating successful STP models like Silicon Valley in regions with differing economic and cultural contexts.	World Bank (2010); Garzoni et al. (2020); Wei et al. (2007)
2.2.2 Role in Innovation	Knowledge Ecosystems and Economic Impact	STPs act as key hubs for knowledge transfer and innovation, enhancing regional economic performance through collaboration with universities and firms.	Risks of exacerbating regional inequalities as innovation and resources concentrate within STPs, limiting diffusion to outlying areas.	Fulgencio (2017); Clarysse et al. (2014); Yan et al. (2020); Germain et al. (2022)
2.3 Collaborative Dynamics	Partnerships among NTBFs, Universities, and Firms	Collaborations in STPs enhance innovation, particularly when NTBFs, universities, and large firms cooperate closely.	Potential issues with transaction costs, particularly with increased presence of large firms, and risks associated with	Myoken (2011); Han (2017); Audretsch et al. (2017); Bruneel et al. (2016)

			knowledge spillovers benefiting competitors.	
2.4 Geographic Clustering	Cluster Effects and Spatial Proximity	Geographic clustering promotes professional networking, knowledge exchange, and innovation; regional clusters seen as advantageous for high-tech firms.	Dependency on geographic proximity is debated; the quality of collaboration and institutional ties also play significant roles beyond spatial clustering alone.	Fioravanti et al. (2023); Hu (2008); Boschma (2005); Pan et al. (2019)
2.5 Technology Transfer Offices	Knowledge Transfer and Commercialisation	TTOs are pivotal for transferring university research to industry, managing IP, and supporting start-up formation, crucial to bridging research and market needs.	TTO success depends on organisational structure, requiring flexibility, empowerment, and strong partnerships with industry stakeholders.	Siegel et al. (2003); Markman et al. (2005); Sutopo et al. (2022); Bercovitz & Feldman (2008)
2.5.3 Triple-Helix Model	Academia-Industry-Government Collaboration	The Triple-Helix model effectively supports high-tech entrepreneurship within STPs, enhancing economic growth and knowledge production.	Criticisms include the model's rigidity, limitations in non-Western contexts, and challenges in adapting to nonlinear, complex innovation dynamics.	Etzkowitz & Leydesdorff (1995); Cai & Etzkowitz (2020); Galvao et al. (2019); Mineiro et al. (2021)
2.6 Success Metrics for STPs	Key Indicators for STP Success	Effective STP evaluation requires collaboration metrics, economic performance indicators, and facility quality; multi-dimensional approaches like balanced scorecards.	Standardisation issues due to STP diversity; indicators often fail to capture dynamic external factors like regional economy or market trends.	Westhead (1997); Ünlü et al. (2023); Tofighi et al. (2017); Hemati & Mardani (2012)
2.7 Evaluation Models	Frameworks for STP Success	Current models focus on intellectual capital, leadership, and regional conditions; tailored frameworks recommended for different STP types.	Existing models often emphasize technology transfer, overlooking aspects like creativity, incubation, and broader regional contextual factors.	Fojs & Detelj (2021); Carayannis et al. (2018); Makhdoom et al. (2022); Nosratabadi et al. (2011)
2.8 STPs in Regional Growth	Regional Economic Development	STPs strengthen regional economies by supporting high-tech clusters, start-ups, and SME growth; incubation and acceleration programs vital for early-stage innovation.	Resource-sharing complexities, need for aligned governance, and balancing support for both mature companies and start-ups in diverse regions.	Sudiana & Hendayani (2020); Lam et al. (2021); Feng et al. (2021); Entringer & Silva (2020)
2.9 Government Investment	Role of Government Funding and Policy	Government investment in STPs is critical for infrastructure, policy support, and talent development, supporting innovation and regional competitiveness.	STP reliance on government funding risks; need for sustainable revenue models and more independent financial structures to reduce vulnerability to policy changes.	Akgün & Güner (2022); Alishiri et al. (2018); Phillips & Yeung (2003); IASP Survey (2022)
2.9.2 Global Impact of STPs	Worldwide STP Landscape and Technological Advancements	STPs widely adopted globally, embedded in economic policies; function as major technology transfer platforms in both developed and emerging economies.	Developing regions face barriers like lack of local resources and skills; potential for international partnerships and policy support remains underexplored.	UN.ESCAP (2019); Walcott (2002); Yang et al. (2018); Yan & Chien (2013)
2.10 Challenges and Unexplored	Challenges in Collaboration and Knowledge Transfer	STPs face challenges in effective stakeholder collaboration, skilled workforce retention, and technology commercialisation.	Limited research on inter-organisational knowledge spillovers, start-up support needs, and regional contextual factors affecting STP performance.	Löfsten et al. (2020); González-Masip et al. (2019); Henriques et al. (2018); Staszków (2016)

Chapter 3-7: Experimental Studies and Analysis

3 Analyses of small and medium-sized STPs show that longer-term growth may depend upon attracting larger partners

3.1 Introduction

Science and Technology Parks (STPs) encourage small innovative start-ups and thus are seen to contribute to regional development (see e.g., Cadorin et al., 2019 for a recent review). One central concept is the collaborative relationship between the university, business and government - known as the "Triple Helix" to foster innovation in STPs. However, a shadow has been cast over the "Triple Helix" model by Johnston and co-workers as well as others [Johnston and Huggins (2018), Johnston (2019) and Johnston (2020), for recent reviews, see also Ng et al., 2019; Lecluyse et al., 2019, as well as Hobbs et al.,2017)] who point out that co-operation between businesses and universities demands very narrow asset specificity. This specificity is present in classical models of Tech Entrepreneurship, when start-ups were spun out of university research labs, but this model may well be becoming outdated, a conundrum supported by the results of Perkmann et al. (2013), who point out in a statistical fashion the difficulties universities experience in attracting research contracts from well-established businesses (Perkmann et al., 2013) and indeed Winters and Stam (2007) point out that such relationships, where they occur, can be relatively void of new innovations.

While individual research labs at universities do come and go, universities themselves tend to be very stable. This is not, however, the case for STPs, where only about ~20% of which are successful, as reported by, e.g. Wadhwa (2013), Kelly and Firestone (2016) and Pugh et al. (2018). This rather dire situation provoked an analysis by Al-Kfairy and Mellor (2020) using two new concepts; firstly, that innovations may have a negative value (Mellor, 2019; Will et al., 2019) and secondly that it is the organisational architecture that determines corporate performance (originally in Sah and Stiglitz, 1986). The adoption of these two new concepts opens the field to analysis using powerful econometric tools, including Structural Equation Modelling (SEM) and Monte Carlo techniques, as well as locational mapping tools using Geographic Information Systems (GIS) and the use of both panel data and Big Data (e.g., Al-Kfairy et al., 2020; Kussainov et al., 2020; Mellor, 2018).

These new results, as presented in a recent overview by Al-Kfairy and Mellor (2020), imply a decision-making tree for start-up STPs where decisions on which innovative new firms to "adopt" and allow to participate in the STP, begin in an *ad hoc* fashion where mistakes are not costly and management costs are not onerous (Mellor, 2016). As the STP grows, poor decisions will scale accordingly and become more costly, eventually leading to STP market failure or a forced re-orientation of the organisation to e.g., hosting general business or incubator services (by e.g., relaxing entry criteria; Albahari et al., 2018). However, correct decision-making by the central STP entity (often referred to as the "Cluster Initiative" or CI) can be strengthened by the inclusion of experienced managers with relevant knowledge from larger firms (see e.g., Wegner and Mozzato, 2019). The trade-off between better decision-making and the transaction costs incurred for this improvement occurs when resources from two larger firms can be drawn upon (Al-Kfairy and Mellor, 2020), even though more than two larger firms may be available.

In order to investigate this hypothesis further, we have chosen to analyse panel data to explore the economic health of firms in smaller STPs with either none, or with 2 larger firms in residence. If the hypothesis is false, then there should be a marked economic similarity between the on-cluster firms in both STPs and between the off-cluster firms in the municipalities but outside the STPs.

3.2 Methodological approach and source of data

Using the Swedish companies' database 'Ratsit.se' (https://www.ratsit.se/), a longitudinal set of panel data was obtained pertaining to the years 2012–2018 and included firms self-identifying with the Swedish Standard Industrial Classification (SNI) industrial code 'J 62' (programming and related industries). Data were obtained and cleaned for all such firms located in Skövde municipality and in Umeå municipality. In each municipality, firms were assigned into one of two groups, called on-cluster and off-cluster, respectively:

a) Each firm, as identified by its Swedish Standard Industrial Classification (SNI) registration number (equivalent to U.K. Companies House registration number) was identified separately in order to match with the firms that are listed on the appropriate Science Park website.
b) Each firm's name was used to search on the Internet to find the location in order to match whether they are located in the same area of the Science Park or not.

Firms in the municipality not mentioned on the STP website and exhibiting a different postal code from the STP address were designated "off-cluster".

3.3 Data comparison between On-cluster and Off-cluster

Following comprehensive data cleaning and sorting procedures, a thorough examination was performed to discern the unique attributes of businesses situated within and outside the cluster. The ensuing analysis yielded illumination results, as shown in Table 3.1. Although the number of companies located beyond the cluster surpassed those within, a substantial disparity arose with respect to total employment figures. Specifically, on-cluster firms displayed a significant advantage over their off-cluster counterparts in both the Science Parks.

The Skövde Science Park, established in 1998, exhibited a substantial concentration of economic activity, with on-cluster firms making a considerable contribution to the municipality's employment landscape. Even though these firms constituted only 30% of the total number of businesses in the Skövde municipality, they accounted for 78% of the overall employment figures in 2018. This disparity is strikingly illustrated by the comparison of firm numbers and employee counts, where the 21 on-cluster firms, excluding branches of two large companies, collectively employed 598 individuals, surpassing 178 employees working in 59 off-cluster firms.

In contrast, Umeå Science Park, founded in 2003, exhibited a distinct profile characterised by a higher proportion of small-scale enterprises. Although it represented only 11% of the municipality's overall firm count, Science Park played a significant role in driving local employment, contributing 29% of the total employment in Umeå municipality. The composition of firms within Umeå Science Park, exclusively comprising small entities as of 2018, highlights its function as a nurturing ground for fledgling ventures and start-ups. Further analysis of employment dynamics within the Umeå municipality reveals a striking contrast between on-cluster and off-cluster firms. On average, on-cluster firms boasted a considerably higher employee count per firm, with an average of 7.42 employees per entity. In contrast, off-cluster firms trailed behind significantly, averaging only 2.14 employees per firm. This disparity underscores the vital role played by the Science Park in fostering employment generation and facilitating the growth and expansion of firms within its remit.

Table 3.1: Comparison of the total number of firms (NOF) and the total number of employees (NOE) in the four categories.

	SKÖVDE SCIENCE PARK				UMEÅ SCIENCE PARK			
Year	Total NOE On-Cluster	Total NOE Off-Cluster	Total NOF On-Cluster	Total NOF Off-Cluster	Total NOE On-Cluster	Total NOE Off-Cluster	Total NOF On-Cluster	Total NOF Off-Cluster
2012	200	27	10	13	51	86	8	50
2013	226	43	17	24	97	152	10	77
2014	303	71	17	27	133	159	13	89
2015	357	62	20	33	141	205	13	103
2016	402	122	20	43	147	267	16	127
2017	502	141	20	48	140	290	17	140
2018	598	168	21	49	135	323	17	138

3.3.1 Firms and Employees Growth Rates Analysis

The annual growth rates for both science parks typically ranged between 12% and 13%, while the average annual growth rates for their employees were between 16% and 18% (as shown in Table 3.2).

Table 3.2: Longitudinal analysis of the number of firms (NOF) and the number of employees (NOE) in the two STPs for the years 2012-2018.

Science Park	Average NOFs Growth Rate (On-Cluster)	Average NOEs Growth Rate (On-Cluster)	Average NOFs Growth Rate (Off-Cluster)	Average NOEs Growth Rate (Off-Cluster)
Skövde	12%	18%	22%	31%
Umeå	13%	16%	17%	22%

Figure 3.1 presents a graphical representation that provides a detailed analysis of the employment patterns in the Skövde and Umeå regions, focusing specifically on on-cluster and off-cluster firms over a period of seven years. Figure 3.1 shows that for Skövde, the employment figures in on-cluster firms demonstrate a substantial increase, with a linear progression of approximately 500% during the observed period. In a similar vein, the employment trend in off-cluster firms exhibits notable growth, characterised by a linear progression of around 200% over the same duration. Despite the significant growth observed in off-cluster employment, the number of employees in on-cluster firms exceeds that in off-cluster establishments, highlighting the dominance and influence of on-cluster firms within the Skövde region's economic landscape.

This finding emphasises the essential role of these firms as major contributors to employment generation and economic activity within the cluster ecosystem.

Figure 3.1 also provides a comprehensive analysis of the employment trends in the Umeå region, encompassing both on-cluster and off-cluster firms over a period of seven years. A noteworthy observation is the substantial expansion of employment in off-cluster firms, which exhibited a linear progression of approximately 300% throughout the observation period. In contrast, while on-cluster firms also experienced an increase in employment, the growth trajectory was relatively modest, reaching around 160% over the same seven-year period. It is important to mention that the growth in on-cluster employment followed a nonlinear pattern, with the rate of increase noticeably diminishing after 2015. The absolute number of employees in off-cluster firms significantly surpassed the number in on-cluster firms (Figure 3.1).

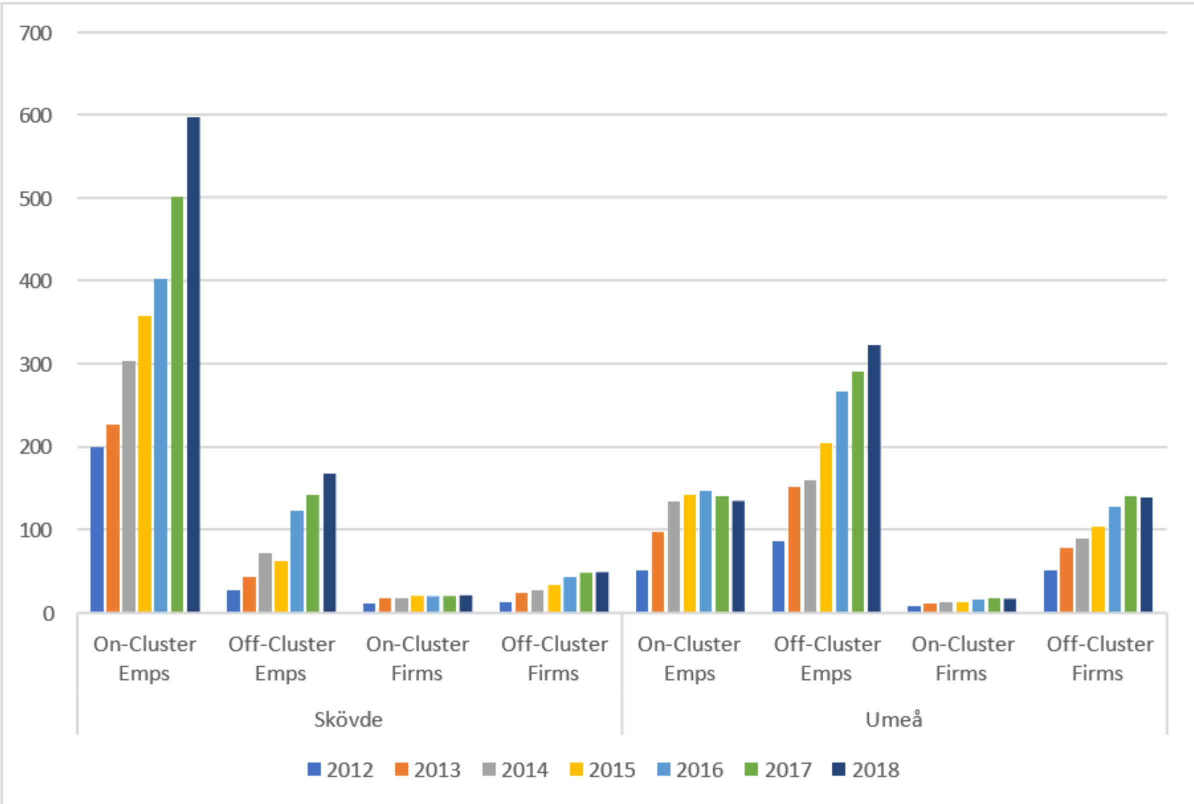


Figure 3.1: Chart illustrating the total Number of Firms (NOF) and total Number of Employees (NOE) for the two municipalities in both on-cluster and off-cluster.

3.3.2 Corporate size-distribution and turnover

Figure 3.1 presents a comprehensive analysis of the relationship between the concentration of businesses in on-cluster and off-cluster locations, which closely aligns with the prevailing employment trends observed within the respective municipalities. Furthermore, a meticulous examination of the data, as depicted in Table 3.3, unveiled fascinating insights into the composition and growth dynamics of firms within the Science and Technology Parks (STPs). It is noteworthy that in both STPs, there is a higher prevalence of micro to small and medium-sized enterprises (SMEs) within the on-cluster framework compared to the off-cluster counterparts. Additionally, Table 3.3 illustrates that within both municipalities, the prevalence of micro-level enterprises is more pronounced off-cluster than on-cluster. However, an intriguing finding from the data suggests that the likelihood of transitioning from a micro to an SME scale is significantly higher within the on-cluster environment compared to the off-cluster setting.

Table 3.3: The distribution of firm size, aggregated between 2012 and 2018, was analysed in terms of the number of firms (NOF) for both STPs, both on-cluster and off-cluster.

	SKÖVDE SCIENCE PARK		UMEÅ SCIENCE PARK	
Group	Total NOFs (On-Cluster)	Total NOFs (Off-Cluster)	Total NOFs (On-Cluster)	Total NOFs (Off-Cluster)
Micro (0-9 Employees)	21	62	16	183
Small (10-49)	10	4	5	11
Medium (50-249)	4	2	0	2

Table 3.4 provides a comparative analysis of the average turnover rates of on-cluster and off-cluster firms within two Science and Technology Parks (STPs). The data reveal the financial performance metrics of businesses operating within these innovation-driven ecosystems and highlight the differential turnover dynamics between on-cluster and off-cluster entities. The results show a consistent trend, where on-cluster firms have significantly higher average annual turnover figures than their off-cluster counterparts in both STPs. This difference indicates a noticeable advantage for on-cluster firms, suggesting that they possess a higher level of financial stability and robustness within the STPs.

Table 3.4: On-cluster and Off-cluster average annual turnover (in thousands of Swedish Kroner) for firms in both STPs.

	SKÖVDE SCIENCE PARK		UMEÅ SCIENCE PARK	
Financial Year	On-Cluster Average Turnover	Off-Cluster Average Turnover	On-Cluster Average Turnover	Off-Cluster Average Turnover
2012	16644	2274.08	4782.88	2306.42
2013	12239	1694.04	6372.5	2393.73
2014	15725.82	2592.74	8594.46	1991.76

2015	17193.05	1762.91	7330.85	1913.98
2016	19695	2170.4	6192.38	2305
2017	25486.5	2597.75	7750.59	2310.46
2018	28228.33	2835.33	7850.82	2729.88

3.3.3 Innovation factors

The data depicted in Tables 3.5 and 3.6 illustrate the expenditure patterns observed within Science and Technology Parks (STPs), particularly in relation to Research and Development (R&D) expenditures and social costs. Notably, firms situated within the cluster display a predilection for allocating greater financial resources to both R&D pursuits and social networking activities in comparison to their counterparts situated outside the cluster across both STPs examined. This disparity highlights the differentiated strategic orientations embraced by companies operating within and beyond the clustered environment, with on-cluster entities exhibiting an enhanced dedication to promoting innovation and fostering social capital within the specialised ecosystem of STPs. By contrast, off-cluster firms exhibit a propensity to allocate significantly fewer resources to social networking endeavours and R&D initiatives.

Furthermore, the data indicate that firms situated within the cluster make a significant contribution to the generation of patents and licences, surpassing those located outside the cluster. The methodological framework used for calculating these figures adheres to the approach outlined by García-Manjón and Romero-Merino (2012). This methodology involves the calculation of innovation growth, in which input factors, such as R&D investment and networking expenses (measured using social expenses data), are combined. The output is then assessed based on the returns obtained from the sale/licensing of patents and the introduction of new products into the market. By adhering to this methodological paradigm, the analysis offers a comprehensive understanding of the complex dynamics underlying innovation within STP environments, thereby emphasising the interdependent relationship between investment in R&D, the development of social networks, and the commercialisation of intellectual property assets.

Table 3.5: Skövde - Finance in thousand Swedish Kroner for on- and off-cluster firms; Total R&D, Social Expenses and Patents and Licenses Income.

SKÖVDE SCIENCE PARK						
Reporting Year	On-Cluster Total R&D	Off-Cluster Total R&D	On-Cluster Total Social Expenses	Off-Cluster Total Social Expenses	On-Cluster Total Patents and Licenses	Off-Cluster Total Patents and Licenses
2012	26006	237	21020	3873	260	22

2013	35516	189	30545	5898	195	0
2014	33161	901	39020	11316	218	0
2015	32989	0	52068	8688	293	30
2016	32199	9135	51733	507	167	0
2017	35805	22020	60528	0	107	0
2018	36090	32719	71227	0	46	0

Table 3.6: Umeå - Finance in thousand Swedish Kroner for on- and off-cluster firms; Total R&D, Social Expenses and Patents and Licenses Income.

UMEÅ SCIENCE PARK						
Reporting Year	On-Cluster Total R&D	Off-Cluster Total R&D	On-Cluster Total Social Expenses	Off-Cluster Total Social Expenses	On-Cluster Total Patents and Licenses	Off-Cluster Total Patents and Licenses
2012	2172	684	5663	18792	70	0
2013	8678	342	12651	34863	108	3
2014	11138	0	15081	24756	109	1
2015	15301	0	18991	43019	159	0
2016	30471	2803	7326	24848	158	90
2017	28218	8305	1392	13702	93	72
2018	29457	8026	2057	15724	45	53

3.4 Statistical analyses

Data was loaded into the software ‘Stata’ where a unique identifier (primary key) used the unique Companies House registration number of each organisation (orgID), associated to the year of the point in question, whereupon the number of employees (NOE) and annual turnover for that year was transformed by using natural logarithmic functions (this is; ln(x) where x is either the NOE or the annual turnover for that year), generating a log series to reduce the heteroscedasticity and using the value of the final variable ‘the ratio of patents to turnover’ to represent the measure of innovation. The results for the two STPs are presented in Tables 3.7 and 3.8.

Table 3.7: Summary of Umeå on-cluster data (Stata screenshot).

Variable	Obs	Mean	Std. Dev.	Min	Max
orgNo	119	5.57e+09	8389332	5.57e+09	5.59e+09
year	119	4.97479	2.249151	1	8
firmAge	119	5.268908	3.588346	0	14
clusterAge	119	12.97479	2.249151	9	16
noEmp	119	8.529412	12.19532	0	54
ln_noEmp	119	1.514027	1.222807	0	4.007333
rdEx	119	1441.731	3609.302	0	18773
ln_rdEx	119	2.292133	3.601251	0	9.840228
socialEx	119	646.4538	1344.69	0	6293
ln_socialEx	119	2.741564	3.351064	0	8.747352
pl	119	6.252101	17.93265	0	92
ln_pl	119	.5475939	1.302281	0	4.532599
turnover	119	7350.924	10969.87	0	49768
ln_turnover	119	6.934053	3.140261	0	10.81515
innov	119	.0015872	.0054508	0	.033714
orgID	119	8.327731	4.824214	1	19
firmAge2	119	40.52941	44.07175	0	196
noEmp2	119	220.2269	491.144	0	2916
socialEx2	119	2210900	6324580	0	3.96e+07
innovLag	100	.0018258	.0058948	0	.033714
turnoverLag	100	7184.31	10803.7	0	49768
socialExLag	100	706.83	1394.248	0	6293
ln_rdExLag	100	2.260598	3.572559	0	9.781207

Table 3.8: Summary of Skövde on-cluster data (Stata screenshot).

Variable	Obs	Mean	Std. Dev.	Min	Max
orgNo	149	5.57e+09	6786170	5.57e+09	5.59e+09
year	149	4.926174	2.205932	1	8
firmAge	149	6.456376	4.918914	0	19
clusterAge	149	17.92617	2.205932	14	21
noEmp	149	21.51007	32.95587	0	172
ln_noEmp	149	2.126351	1.489813	0	5.153292
rdEx	149	1907.839	5304.151	0	27332
ln_rdEx	149	2.110503	3.568864	0	10.21585
socialEx	149	3227.342	7601.577	0	47283
ln_socialEx	149	3.490864	4.02075	0	10.76393
pl	149	8.630872	37.73241	0	260
ln_pl	149	.32392	1.185549	0	5.56452
turnover	149	26354.79	45048.59	0	205401
ln_turnover	149	8.112227	3.042399	0	12.23272
innov	149	.0005086	.0030068	0	.0278019
orgID	149	10.95973	6.035793	1	24
firmAge2	149	65.71812	81.69473	0	361
noEmp2	149	1541.483	4133.289	0	29584
socialEx2	149	6.78e+07	2.68e+08	0	2.24e+09
innovLag	125	.0006062	.0032758	0	.0278019
turnoverLag	125	24654.73	40519.14	0	171755
socialExLag	125	3215.176	6988.933	0	41546
ln_rdExLag	125	2.023177	3.52189	0	10.13388

The 'Stata' software was employed to derive both linear and quadratic representations. Individual variables were introduced one by one, utilising the technique detailed by Al-Kfairy et al. (2019b and 2020). After each variable was added, new p-values were calculated. The optimal model was determined through a trial-and-error process, with factors identified from the literature as potentially relevant. Subsequently,

a) The variables were either accepted or rejected based on their p-values, where a p-value >0.05, led to rejection.

b) The overall p-values and R2-adjusted values were evaluated for both the linear and quadratic models for each variable.

c) Hausman tests were then applied to differentiate between the fixed and random effects.

The above steps were performed on both on-cluster and off-cluster firms and, where significant p-values were found, the Hausman step would also be invoked. This methodology enabled the identification of those factors that influence the development of firms at the micro level for all firms (micro and SME) in both municipalities, and then to compare on-cluster with off-cluster firms.

3.4.1 Econometric investigation of employment growth

Organizational growth was investigated using firms age and innovation output. Absolute values were used for both linear and quadratic regressions, as in Equation 3.1:

$$ln(emp_{i,t}) = B1 \times firmAge^2_{i,t} + B2 \times firmAge_{i,t} + B3 \times innov_{i,t-1} + B4 \times turnover_{i,t-1} + U_i$$

Equation 3.1: Firms Employment Growth Regression (prediction) Model

In equation 3.1, Age is the firm age in any year and the turnover in the previous year is (t – 1). Innovation in the previous year was calculated as in equation 3.2:

$$Innov_{i,t} = \frac{TPV_{i,t}}{Turnover_{i,t}}$$

Equation 3.2: Innovation Indicator Equation

and in equation 3.2, TPV = the Total Patent Value in year (t) of the patents of the firm (i)

In order to differentiate between random and fixed effects, Hausman tests were used, and in these cases, the test returned a chi2 of 0.0025 for Umeå and a chi2 of 0.0366 for Skövde, indicating that a fixed effect model should be used. The results for both STPs are shown in tables 3.9 and 3.10.

Table 3.9: Hausman test results from Umeå on-cluster data (Stata screenshot).

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
firmAge2	-.0165562	-.0208605	.0043043	.
firmAge	.2226398	.3127473	-.0901075	.
innovLag	38.83334	36.10683	2.726508	1.907068
turnoverLag	.0000245	.0000424	-.0000179	3.75e-06

```
                  b = consistent under Ho and Ha; obtained from xtreg
   B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic

              chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                      =       14.32
            Prob>chi2 =      0.0025
            (V_b-V_B is not positive definite)
```

Table 3.10: Hausman test results from Skövde on-cluster data (Stata screenshot).

	Coefficients (b) fixed	(B) random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
firmAge2	-.0047628	-.0058714	.0011086	.0004676
firmAge	.1872849	.2036594	-.0163745	.0069116
innovLag	-11.13164	-10.67051	-.4611219	1.657769
turnoverLag	5.01e-06	7.48e-06	-2.48e-06	8.06e-07

```
                  b = consistent under Ho and Ha; obtained from xtreg
   B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic

              chi2(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                      =        8.51
            Prob>chi2 =      0.0366
```

Having established that a fixed-effect model should be used, the effects of firm age, innovation and annual turnover can be calculated for Umeå on-cluster firms (table 3.11), Umeå off-cluster firms (table 3.12), Skövde on-cluster firms (table 3.13) and Skövde off-cluster firms (table 3.14). For Umeå, table 3.11 (on-cluster) and 3.12 (off-cluster) evaluate the correlation between firms' employment growth, age, previous year turnover and previous year innovation output, showing that firm previous year innovation has a positive correlation with firms' employment growth on-cluster (table 3.11) but had the opposite effect in off-cluster firms (table 3.12).

Table 3.11: Fixed & random effects obtained from equation (3.1) for employment growth amongst Umeå on-cluster firms.

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($firmAge^2{}_{i,t}$)	-.0165562 (0.003)	-.0208605 (0.000)
B2 ($firmAge_{i,t}$)	.2226398 (0.004)	.3127473 (0.000)
B3 ($innov_{i,t-1}$)	38.83334 (0.006)	36.10683 (0.008)
B4 ($turnover_{i,t-1}$)	.0000245 (0.017)	.0000424 (0.000)
Constant	.8177424 (0.001)	.3255458 (0.185)

Table 3.12: Fixed & random effects obtained from equation (3.1) for employment growth amongst Umeå off-cluster firms.

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($firmAge^2 i,t$)	-.0018953 (0.028)	-.0017063 (0.053)
B2 (firmAgei,t)	.0290647 (0.018)	.022975 (0.065)
B3 (innovi,t-1)	-.9500225 (0.751)	-.6905391 (0.823)
B4 (turnoveri,t-1)	.0000255(0.000)	.0000395 (0.000)
Constant	.4671913 (0.000)	.4910257 (0.000)

A different outcome can be seen in Skövde compared to Umeå (table 3.13 and table 3.14), where firm previous year innovation has a negative impact on firm employment growth both on- and off-cluster. On-cluster, firms last year turnover has a strong positive correlation with firm employment growth. Firm current age also shows a positive impact on employment growth in on-cluster (implying the young on-cluster firms are growing) but was negative off-cluster.

Table 3.13: Fixed & random effects obtained from equation (3.1) for employment growth amongst Skövde on-cluster firms.

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($firmAge^2{}_{i,t}$)	-.0047628 (0.012)	-.0058714 (0.002)
B2 ($firmAge_{i,t}$)	.1872849 (0.000)	.2036594 (0.000)
B3 ($innov_{i,t-1}$)	-11.13164 (0.312)	-10.67051 (0.356)

B4 ($turnover_{i,t-1}$)	5.01e-06 (0.018)	7.48e-06 (0.000)
Constant	1.22639 (0.000)	1.053271 (0.000)

Table 3.14: Fixed & random effects obtained from equation (3.1) for employment growth amongst Skövde off-cluster firms.

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($firmAge^2{}_{i,t}$)	.0005235 (0.563)	.0005243 (0.590)
B2 ($firmAge_{i,t}$)	-.0215008 (0.198)	-.0205331 (0.246)
B3 ($innov_{i,t-1}$)	-.0042087 (0.873)	-.0062741(0.828)
B4 ($turnover_{i,t-1}$)	.0000281 (0.000)	.0000348 (0.000)
Constant	.7837963 (0.000)	.7685335 (0.000)

3.4.2 Econometric model of financial growth

Modelling the general economic growth was similar to before (see equation 3.1), but modified as shown in equation (3.3) below:

$$ln(turnover_{i,t}) = B1 \text{ x } Emp^2 \; + B2 \text{ x } Emp_{i,t} + B3 \text{ x } firmAge^2 \; + B4 \text{ x } firmAge_{i,t} + B5 \text{ x } ln(socialEx_{i,t}) \; U_i$$

Equation 3.3: Financial Growth Regression Model

Hausman tests were used as before, resulting in these cases in a value chi2 of 0.7147 for Umeå and a chi2 value of 0.1537 for Skövde, indicating again that a fixed effect model should be used.

Table 3.15: Hausman test result of Umeå on-cluster data (Stata screenshot).

	(b) fixed_t	(B) random_t	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
noEmp2	-.0020481	-.0026775	.0006295	.0005195
noEmp	.1591231	.1897007	-.0305776	.0436708
firmAge2	-.0436843	-.0402764	-.003408	.0040854
firmAge	.8752184	.795304	.0799145	.0653867
ln_socialEx	.1628657	.1363904	.0264752	.0369927

```
                   b = consistent under Ho and Ha; obtained from xtreg
    B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic

              chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                      =        2.90
            Prob>chi2 =      0.7147
```

Table 3.16: Hausman test result of Skövde on-cluster data (Stata screenshot).

	(b) fixed_t	(B) random_t	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
noEmp2	-.0001411	-.0001281	-.0000129	.0000786
noEmp	.0409373	.0453319	-.0043946	.0206309
firmAge2	-.0493923	-.0526401	.0032479	.0022426
firmAge	1.247506	1.168995	.0785112	.0516746
ln_socialEx	.2598964	.1935849	.0663115	.0240943

```
                   b = consistent under Ho and Ha; obtained from xtreg
    B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test:  Ho:  difference in coefficients not systematic

              chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                      =        8.05
            Prob>chi2 =      0.1537
            (V_b-V_B is not positive definite)
```

Table 3.17: Umeå on-cluster firms: turnover growth from equation (3.3).

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($Emp^2_{i,t}$)	-.0020481 (0.156)	-.0026775 (0.045)
B2 ($Emp_{i,t}$)	.1591231 (0.045)	.1897007 (0.003)
B3 ($firmAge^2_{i,t}$)	-.0436843 (0.002)	-.0402764 (0.003)
B4 ($firmAge_{i,t}$)	.8752184 (0.000)	.795304 (0.000)
B5 ($ln(socialEx_{i,t})$)	.1628657 (0.034)	.1363904 (0.039)
Constant	2.740415 (0.000)	3.074855 (0.000)

Table 3.18: Umeå off-cluster firms: turnover growth from equation (3.3).

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($Emp^2_{i,t}$)	-.0032505 (0.000)	-.0039976 (0.000)
B2 ($Emp_{i,t}$)	.344573 (0.000)	.3785418(0.000)
B3 ($firmAge^2_{i,t}$)	-.0099408 (0.033)	-.014115 (0.002)
B4 ($firmAge_{i,t}$)	.1531095 (0.015)	.2127176 (0.000)
B5 ($ln(socialEx_{i,t})$)	.1544821(0.000)	.1819912 (0.000)
Constant	3.877198 (0.000)	3.598174 (0.000)

Table 3.17 (on-cluster) and table 3.18 (off-cluster) review the relationship between firms' financial growth, size, age and social expenses in Umeå. The financial growth was evaluated against firm size, firms age and social networking cost. Firm's size, age, and social expenses correlate positively with firm financial growth in both on-cluster and off-cluster firms. Firm age and social networking costs have a greater positive impact in on-cluster firms than in off-cluster firms. However, when on-cluster firms grow older, the p-value grows less. This phenomenon also occurs in off-cluster firms, but to a lesser extent than on-cluster.

Table 3.19: Skövde on-cluster firms: turnover growth from equation (3.3).

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($Emp^2_{i,t}$)	-.0001411 (0.309)	-.0001281 (0.260)
B2 ($Emp_{i,t}$)	.0409373 (0.166)	.0453319 (0.030)
B3 ($firmAge^2_{i,t}$)	-.0493923 (0.000)	-.0526401 (0.000)
B4 ($firmAge_{i,t}$)	1.247506 (0.000)	1.168995 (0.000)
B5 ($ln(socialEx_{i,t})$)	.2598964 (0.000)	.1935849 (0.000)
Constant	1.73345 (0.001)	2.561151 (0.000)

Table 3.20: Skövde off-cluster firms: turnover growth from equation (3.3).

Parameter	Fixed effect (p-value)	Random effect (p-value)
B1 ($Emp^2{i,t}$)	-.0036799 (0.000)	-.0036907 (0.000)
B2 ($Emp_{i,t}$)	.3576381 (0.000)	.3577384 (0.000)
B3 ($firmAge^2{i,t}$)	-.0098772 (0.029)	-.0124964 (0.005)
B4 ($firmAge_{i,t}$)	.155172 (0.050)	.2298347 (0.002)
B5 ($\ln(socialEx_{i,t})$)	.1029694 (0.047)	.1385474 (0.004)
Constant	4.045259 (0.000)	3.501768 (0.000)

A similar scenario can be seen in Skövde (see Table 3.19 and Table 3.20), where firm size, age, and social networking cost positively correlate with financial growth, although firm size shows a poor p-value in on-cluster firms, and as firms grow more, the p-value decreases more in on-cluster firms than off-cluster firms.

In both STPs there is a financial slow-down when firms get older, and this plateaux-out effect is more pronounced on-cluster.

3.5 Results and Discussion

The results presented here show that small firms (micro and SMEs) are generally better able to grow and prosper on-cluster than off-cluster, a finding that is largely in accordance with previous findings (see Mellor, 2020, as well as the results presented by Al-Kfairy et al., 2019b), who analysed the large and well-established Mjärdevi Science Park in the Linköping municipality. When the economic health of the on-cluster firms is good, then (as seen in the case of Skövde), the off-cluster firms appear to benefit as well; in the Skövde municipality, on-cluster employment increased by 42% p.a. on average, and by 88% p.a. on average off-cluster. Indeed, it is possible that off-cluster firms may be suppliers to on-cluster firms or otherwise be part of a supply chain for some on-cluster firms, as postulated for the Mjärdevi Science Park in the Linköping municipality (Al-Kfairy et al., 2019b).

Figure 3.1 shows that the average on-cluster firm in Skövde Science Park had 21 employees compared to three employees per off-cluster firm. In Umeå Science Park, each on-cluster firm had nine employees on average compared to two employees per off-cluster firm (figure 3.1).

In the case of Umeå, off-cluster growth in employment is moderately strong (54% p.a. on average) whilst on-cluster employment seems to have plateaued-out (37.5% p.a. on average, see figure 3.1). The lower growth seen in the case of Umeå could be due to several factors. In the Innovation-Based Theory of the firm (Mellor, 2015; Costello, 2019), firms can be thought of as vehicles for innovations. How STPs choose innovations (that is, to choose innovative firms to inhabit their STP) thus becomes of prime importance and choosing badly can be very expensive (Mellor, 2019, Will et al., 2019). According to Al-Kfairy and Mellor (2020), this decision-making is helped when branches or divisions of large firms are present, whose in-depth knowledge improves decision-making regarding inhabitancy. In the Skövde STP, two large firms (Volvo and PwC) have a presence via branches of the main firms, while the Umeå STP has none. This relationship is casual and cannot be proven to be causal, but nevertheless, the experiments performed here, and the statistical results reported certainly do not disprove the Al-Kfairy and Mellor (2020) viewpoint. This is underlined by off-cluster employment being approximately similar amongst the off-cluster firms in both municipalities, implying that if the off-cluster "background" is similar in both of the municipalities, then the differences in STP growth may be a function of the properties of the STPs themselves, and one difference is the presence of two large companies the well-performing Skövde STP, although these two large firms are not mainly in industrial code 'J 62'.

Off-cluster firms reported few patents and licences in both municipalities. The majority of patents and licences lay with the on-cluster firms in both cases (tables 3.11-3.14). Interestingly, R&D expenditure in on-cluster firms did not correspond well to the results of R&D; patents and licences (see section 3.4). Clearly, annual R&D expenditure may well not correspond to IPR in the same year, but even plotting previous year and previous two-year expenditure did not give a good correlation either (Tables 3.17 and 3.19 comparing Umeå and Skövde on-cluster firms, and tables 3.18 and 3.20 for the same off-cluster). Conversely, plotting social and networking expenses against patents and licences gave a much better correlation (see Tables 3.5 and 3.6 and the statistical analysis of these as shown in section 3.4) and this finding again, is broadly in agreement with previous results (Al-Kfairy et al., 2019b) for a large STP.

As Al-Maadeed and Weerakkody (2016) point out, in the "classical" Triple Helix theory (Etzkowitz and Leydesdorff, 2000; Leydesdorff and Etzkowitz, 2006), the main functions of the knowledge-based economy are: (1) to generate economic wealth, (2) to generate scientific and technological innovation, and (3) to control the previous two functions at the system level. However, the order in which of these three functions of the Triple Helix is invoked, is poorly addressed within the Triple Helix theory context; in real life, some are provoked by pressing need (e.g., Covid), some are initiated by the commercialisation of university research (e.g., Oxford Nanopore) and others are industry-led (e.g., Space-X). This variable nature of initiation is problematic for the classical view of STP development (Ketels, 2017), which expects mainly university spin-outs or possibly other high-tech firms occasionally needing university research input. To this, one must now add:

a) the concept that innovations (for example, accepting an innovative firm that does not fit well into the main theme of that STP) may give rise to an expensive negative outcome (Mellor, 2019; Will et al., 2019),
b) that Johnston and Huggins (2018), Johnston (2019) and Johnston (2020) found that interactions between universities and business are often suboptimal due to narrow asset specificity and
c) that on-cluster firms can take advantage of new technology to remove themselves from STP premises to adjoining locales that suit them better (Kussainov et al., 2020).

Taken all together, the above factors mean that the classical model of STP development, as espoused for example by Ketels (2017), may well be in need of revisiting.

The decision-making structure of start-up and growing STPs has been analysed from a transaction cost perspective, and results (Al-Kfairy et al., 2020) showed that in early developmental stages, the central organisation (often referred to as the "Cluster Initiative" or CI) co-ordinates the on-cluster firms directly and organises the space they inhabit. However, To avoid "lock-in" with old technology and to keep abreast of trends, STPs need a regular influx of innovative – often small – firms with new ideas (see Cadorin, 2020), and Al-Kfairy and Mellor (2020) have gone on to postulate that when decisions about new inhabitants are to be made, then the CI may often lack the essential specialist knowledge about, e.g. future industry trends and thus, that within the first approximately twenty years of STP history (please note that Umeå Science Park not 20 years old yet), the STP needs to recruit large firms whose managers possess a very high degree of specialist technical insight in order to bolster CI decision-making about recruiting new firms. Without such insight then, as the STP grows, poor decisions will become more costly and lead to market failure and indeed globally as well as in the UK, most STPs fail to grow (Wadhwa, 2013; Pugh et al., 2018; Kelly and Firestone, 2016). Alternatives to market failure include a forced re-orientation to, for example, hosting specialist early-stage incubator services or going down the pathway of abandoning high-tech entrepreneurship altogether and hosting general businesses as a “business park” (Albahari, et al., 2018).

3.6 Future directions

The new results presented here are part of our ongoing contribution towards a "road map" to help the ecosystem of high-tech entrepreneurship and especially STP decision- making and consequences for regional policy. The present work can be expanded upon both laterally and vertically: Here, we took panel data for Swedish Standard Industrial Classification (SNI) firms in industrial code ‘J 62’ (programming and related industries) to look at the expanding area of computing, Internet and eCommerce. From this, a lateral integration could be, for example, repeating the analyses using data from 'M 72' (scientific research and development) to endeavour to capture the situation with biotechnology and medical biotechnology. The drawbacks that we have experienced are that with small STPs and few firms, there may be issues with having only a modest base of the data and possible knock-on effects on statistical significance. One alternative could be to use a vertical strategy and move to analysing larger and well-established STPs.

Contribution of the Chapter

This study provides essential insights into the long-term sustainability and growth of small and medium-sized Science and Technology Parks (STPs), emphasizing the critical role of large firms in stabilizing the STP ecosystem and enhancing decision-making processes. Through an analysis of Skövde and Umeå STPs, the research demonstrates that large firms, by offering expertise and specialized resources, strengthen the central Cluster Initiative (CI) and support smaller innovative firms. Econometric analysis, including Structural Equation Modelling (SEM) and panel data methods, shows that on-cluster firms with large partner involvement experience stronger economic performance, higher employment, and superior innovation outcomes compared to off-cluster firms. Expanding on the traditional Triple Helix model, the study highlights how partnerships with larger firms mitigate risks and reduce failure rates in young STPs, offering a framework for regional policy to foster high-tech entrepreneurship and a sustainable innovation ecosystem.

4 Modelling the number of client firms needed to support a new Science Park and the spacing between new Parks and existing Parks with similar themes.

4.1 Introduction

Science and Technology Parks (STPs) are curated locations where New Technology-Based Firms (NTBFs) and other SMEs can conglomerate and promote a culture of innovation (for review, see Lecluyse et al., 2019). They are often used by regional planners as a strategy to stimulate economic growth (Lindelöf and Löfsten, 2003) around new, innovative products, and have been postulated to exhibit various positive effects, including ameliorating the effects of recession (Taylor, 2009). Traditionally, they are assumed to be associated with a nearby university as knowledge source (see Lecluyse et al., 2019).

The recent vaccine efforts around SARS-CoV-2 virus (COVID-19) technology transfer with prominent actors including Oxford University and also the NTBF BioNTech prompted us to investigate into how universities, innovative firms and STPs active in the pharmaceutical sector, can associate together and function to bring new products to the market. This behaviour is the heart of the so-called "Triple-Helix" model (Etzkowitz and Leydesdorff, 1995). However, a host of metrics pertaining to setting up new STPs appear to be missing from the "Triple-Helix" model (Etzkowitz and Leydesdorff, 2000). These include:

1) The population density of New Technology-Based Firms (NTBFs) and other SMEs involved in researching specific topics in the locale around the STPs, that enable the STP to acquire critical mass and to function,
2) The number of specialised firms (which could be acquiring specialised knowledge or graduates) around universities,
3) The degree of separation between STPs, because these may essentially be competing, and
4) Degree of co-location between STPs and universities as knowledge sources, which is also relevant to the topic of enterprise development in universities.

These metrics are all important for successful technology transfer and the start-up and development of an STP into a thriving tech entrepreneurship ecosystem. In government supported STPs generally, the central co-ordinating bodies (often referred called the “Cluster Initiative” or “CI”) make decisions about which firms can inhabit that STP. Wegner and Mozzato

(2019) speculate that CI decision-making is improved where experienced managers from larger firms can be involved. Using structural equation models (SEM), Monte-Carlo modelling and panel data from a large IT-oriented STP, Al-Kfairy et al. (2020) and Al-Kfairy and Mellor (2020) narrowed this figure down to two such larger firms (more may be present in an STP, however involving >2 increases the transaction costs). This finding was supported by Mondal and Mellor (2021), who used SEM and panel data for STPs with zero or two larger firms in residence, showing that growth as e.g., number of on-cluster employees, was far healthier in the STP with the presence of two large companies.

Nonetheless, Wadhwa (2013), Kelly and Firestone (2016) and Pugh et al. (2018) report that overall, only about 20% of start-up STPs are successful, despite often having promising technology (e.g., Roberts et al., 1980). Clearly this needs to be understood in order to avoid negative e.g., "backwash" effects (see e.g., Mellor, 2021). A further shadow on the "Triple-Helix" model has been cast by Perkmann et al. (2013), who used a large-scale statistical analysis exposing that universities experience great difficulty in attracting research contracts from established businesses, independently of whether these were located within STPs or not. Winters and Stam (2007) go further and point out that university-industry collaborations can be relatively void of new innovations. It may be that a part of the answer is the very high asset specificity needed for fruitful co-operations between industry and universities, as noted by various authors [Hobbs et al. (2017), Johnston and Huggins (2018), Johnston (2019), Ng et al. (2019), Lecluyse et al. (2019), Johnston (2020)].

We have adopted a focused and data-driven approach to address issues in technology transfer, problems like COVID-19, research impact metrics, as well as the implementation of start-up STPs generally in regional development and in government policymaking. In this report, we use:

a) firms active in the UK pharmaceutical industry,
b) university departments scoring highly in pharmacy, and
c) STPs specialised in the pharma/biomed area,

as experimental factors in a virtual model to determine success parameters for small and medium STPs.

In this work, Albahari et al. (2018) is taken as point of departure because "*firms in less technologically developed regions benefit more from location in an STP*" (Albahari et al., 2018, p143) and thus we have taken a relatively abstracted model and used that to reach general conclusions for an imaginary and sparsely populated landscape. In this model we endeavour to estimate how many specialised firms are required in the locale to support the creation of a new and similarly specialised STP. This approach also yields estimates as to how close a new and specialised STP can be to established STPs with a similar specialization, compared to STPs with different specialisations.

4.2 Methodology and Data Sources

UK firms active in pharma and biomed sectors were identified by taking all UK firm data from Gov.uk (2021), cleaning it (e.g., removing dissolved entities, etc.) and selecting those self-identifying with SIC codes 21100 and 21200. There were 1197 firms self-identifying as being in SIC code 21100 (Manufacture of Basic Pharmaceutical Products) and 520 firms self-identifying as being in SIC code 21200 (Manufacture of Pharmaceutical Preparations).

UK STPs active in pharma and biomed were identified from the website of the UK Science Parks Association (“UKSPA”). From the "over 100 Innovation Locations" (UKSPA, undated) and 27 could be identified as specialising in pharma and biomed (table 4.1).

UK universities active in pharma and biomed were identified from the REF 2014 (UK Research Excellence Framework, www.ref.ac.uk/2014), tables as being active in Unit of Assessment (UoA) 3 (Allied Health Professions and Pharmacy) and from the 95 listed, the 26 highest impacting (as judged by the aggregated number of internationally recognised publications being over 100) were used (table 4.2).

Statistical analyses were performed in Stata (www.stata.com). Data manipulations were done in Excel and in ArcGIS-Pro (www.esri.com/en-us/arcgis/products/arcgis-pro/overview). Using ArcGIS-Pro a circle of radius 7.89 km was drawn around each object (STP or university), and the number of companies from the Companies House data were counted. That circle radius was set because Kussainov et al. (2020), using IT-oriented STPs and biomed-oriented STPs previously showed that on-cluster firms migrating to off-cluster locations, moved to an annular zone between 4 and 7 km away from the STP. Thus the 7.89 radius encompasses such distances with a slight margin of error, as well as that the area, 200 square km, facilitates population density measurements.

Table 4.1: Shows the STPs used in this work. Companies include both on-cluster and off-cluster. Note there may be many more companies associated with any STP, but these other firms have different SIC codes. An asterisk (*) shows that the associated Universities did not return in UoA3 in the 2014 REF.

STP specialised in pharmaceutical/ biomedical research: Name	Postcode	Number of companies with SIC codes 21100 and 21200 within 7.98 km of the postcode.
Imperial College Incubator *	W12 0BZ	241
Birmingham Research Park	B15 2SQ	34
Manchester Science Partnerships	M15 6SE	31
Cambridge Biomedical Campus *	CB2 0AA	27
Cambridge Science Park *	CB4 0FZ	27
Liverpool Science Park	L3 5TF	24
Cardiff Medicentre	CF14 4UJ	19
BioCity Group Ltd	NG1 1GF	16
Sussex Innovation Centre	BN1 9SB	11
Wellcome Genome Campus	CB10 1SA	10
Oxford Science Park *	OX4 4GA	9
University of Glasgow - Clinical Innovation Zone	G12 8QQ	6
Chesterford Research Park	CB10 1XL	7
Oxford BioEscalator *	OX3 7FZ	7
University of Wolverhampton Science Park	WV10 9RU	6
West of Scotland Science Park	G20 0SP	6
Charnwood Campus	LE11 5RB	6
Milton Park	OX14 4RY	6
Edinburgh Technopole	EH26 0BB	5
RoCRE	AL5 2JQ	5
Stevenage Bioscience Catalyst	SG1 2FX	5
Unit DX	BS2 0XJ	2
Hethel Innovation	NR14 8FB	2
Lincoln Science and Innovation Park	LN6 7FL	2
Porton Science Park	SP4 0BF	1
The OpTIC Technology Centre	LL17 0JD	1
Wilton Centre	TS10 4RF	1

Table 4.1 shows that a total of 517 firms were detected (average 19.15 per STP) with a standard deviation (SD) of 45.41. The only outlier being Imperial College Incubator, presumably because its 7.89 radius covers a large swathe of London and hence encompasses very many firms.

Table 4.2: Shows the first selection of 26 universities used in this work. The cut-off point is when the number of REF submissions falls below 100.

Top-ranked universities in UoA 3	Postcode	Number of companies with SIC codes 21100 and 21200 within 7.98 km of the postcode.
University of Sheffield	S10 2TN	5
Swansea University	SA2 8PP	6
University of Southampton	SO17 1BJ	4
University of Manchester	M13 9PL	29
University of Bath	BA2 7AY	3
University of Nottingham	NG7 2RD	12
Cardiff University	CF10 3AT	19
University College London (UCL)	WC1E 6BT	323
Aston University	B4 7ET	39
University of Stirling	FK9 4LA	1
University of East Anglia	NR4 7TJ	0
University of Strathclyde	G1 1XQ	6
University of Surrey	GU2 7XH	3
Queen's University Belfast	BT7 1NN	11
Queen Mary University of London	E1 4NS	285
King's College London	WC2R 2LS	323
University of Bristol	BS8 1TH	4
Keele University	ST5 5BG	1
Newcastle University	NE1 7RU	6
Lancaster University	LA1 4YW	0
University of Nottingham	NG7 2RD	12
University of Brighton	BN2 4AT	12
University of Sussex	BN1 9RH	11
University of Leeds	LS2 9JT	12
Bangor University	LL57 2DG	0
University of Bradford	BD7 1DP	11

Table 4.2 shows that 1138 firms were detected (average 43.77, SD = 98.78). The outliers Queen Mary University of London, University College London (UCL) and King's College London all have high numbers, presumably because their 7.89 km radius covers a large swathe

of London. However, Aston University and University of Manchester are less prominent outliers too.

4.3 Results and Discussion

Table 4.2 shows that the predominant universities as shown by REF 2014 ranking showed no particular correlation with the numbers of firms surrounding them. The obvious feature that was revealed, however, is that location is the largest factor, with London universities; Kings, UCL and Queen Mary, dominating the table, accounting for 931 out of 1138 (over 81 %). This figure is actually a larger figure, because UoA3 universities not in the top 26, but still in London, included City University London (EC1V 0HB), which had 209, the University of Greenwich (SE10 9LS) had 89, and the University of Westminster (W1B 2HW) had 189 firms in their respective surrounding areas.

The old established industrial centres also scored well; the highly ranked Aston University (Birmingham) scored well, which can be combined with the (unranked) University of Birmingham (B15 2TT), which had 33. The University of Manchester scores highly when combined with the unranked Manchester Metropolitan University (M15 6BH) with 26, as did South Wales (Cardiff and Swansea, together 25) and the Leeds/Bradford area (23 combined) equal with Sussex/Brighton (23 combined). Numbers under these are presumed to represent the background.

Table 4.1 shows, in agreement with Table 4.2, that the vast majority of activity occurs in London-based STPs, with STPs in Birmingham and Manchester also showing strongly. South Wales and Sussex/Brighton STP activity also correlate with the corresponding university profiles. In table 4.1, Imperial, Oxford and Cambridge STPs have a powerful showing, albeit that the corresponding universities did not submit in UoA3 (REF, 2014), which obviously skews the results in these 3 cases, but because these 3 STPs are not starting up small and mid-sized STPs, then the overall conclusions as pertaining to new start-up STPs, will not be affected.

In order to investigate university – STP spatial relationships, any university within 7.89 km was identified, and in many cases, there were multiple universities within this radius. The distance to the nearest university was also determined. In accordance with our “anonymised” model, the size and perceived success of the entities was not taken into account. The results are shown in Table 4.3, where asterisk (*) shows that the associated Universities do not return in UoA3 in the 2014 REF.

Table 4.3: The mean distance between Science and Technology Parks (STPs) specialising in pharma and universities ranked highly in pharma.

STP specialised in pharmaceutical/ biomedical research: Name	Number of pharma top 26 UoA3 universities within 7.98 km	Distance in km to the nearest UoA3 top 26 university	Distance in km to the nearest university (any uni)
Imperial College Incubator	3	6.37	2.9
Birmingham Research Park	2	0.56	0.56
Manchester Science Partnerships	2	0.58	0.58
Cambridge Biomedical Campus	0 *	49.96	3.66
Cambridge Science Park	0 *	55.05	3.73
Liverpool Science Park	0	49.22	0.13
Cardiff Medicentre	1	1.92	1.92
BioCity Group Ltd	2	1.15	1.15
Sussex Innovation Centre	2	0.3	0.3
Wellcome Genome Campus	0	46.45	14.79
Oxford Science Park	1	4.24	4.24
University of Glasgow - Clinical Innovation Zone	3	On-campus	
Chesterford Research Park	0	47.13	18.39
Oxford BioEscalator	1	0.54	0.54
University of Wolverhampton Science Park	0	20.66	1.62
West of Scotland Science Park	3	3.67	3.67
Charnwood Campus	0	17.78	2.06
Milton Park	0	15.6	15.33
Edinburgh Technopole	0	54.74	7.19
RoCRE	0	8.48	8.48
Stevenage Bioscience Catalyst	0	14.4	14.4
Unit DX	1	2.46	2.46
Hethel Innovation	0	8.61	8.61
Lincoln Science and Innovation Park	1	0.43	0.43
Porton Science Park	0	32.25	28.99
The OpTIC Technology Centre	0	43.76	38.71
Wilton Centre	0	55.22	8.69

Table 4.3 shows that 20.06 km (SD 21.39) was the average distance between STPs specialising in pharma and universities ranked highly in pharma, but that many other universities that are less specialised were much closer, namely average 7.17 km (SD 9.43). The only outliers were Porton Science Park and The OpTIC Technology Centre, both of which are located very

far from Higher Education Institutes, specialised or otherwise. This lack of correlation between STPs and Universities tends to lend a degree of support to the findings of other authors [Hobbs et al. (2017), Johnston and Huggins (2018), Johnston (2019), Ng et al. (2019), Lecluyse et al. (2019), Johnston (2020)].

Rodríguez-Pose and Comptour (2012, p280) say "*Physical proximity is often regarded as the key aspect making some regions genuine loci of innovation. The basic reasoning is that innovation travels with difficulty and suffers from strong distance decay effects*". Using the concepts of distance decay (Pun-Cheng, 2016), Helmers (2019, p31) also found "*knowledge spillovers decay rapidly with geographic distance*". Thus, in order to see if “on campus” STPs closer to knowledge sources were more successful, STPs with less than 2 km distance (in accordance with the results of previous measurements, see Buzard et al., 2017) to a UoA3 university were taken and the number of firms taken from table 4.1. The 127 firms found result in an average of 15.875 firms per on-campus STP.

Table 4.4: Number of firms per on-campus STP as compared with “parent” university.

STP defined as “On-campus” because the postcode <2 km from the university	Number of companies around the STP	Number of companies around the UoA3 university
Cardiff Medicentre	19	19 (Cardiff)
BioCity Group Ltd	16	12 (Nottingham)
Manchester Science Partnerships	31	29 (Manchester)
Birmingham Research Park	34	39 (Aston)
Oxford BioEscalator	7	Oxford: Not returned in UoA3
Lincoln Science and Innovation Park	3	Lincoln: Not returned in UoA3
Sussex Innovation Centre	11	11 (Sussex)
University of Glasgow - Clinical Innovation Zone	6	6 (Strathclyde)

Table 4.4 shows that on-campus STPs (average 15.88) were not significantly more successful or less successful than other STPs (average 19.15) in attracting NTBFs and SMEs, perhaps underlining that close physical associations with a university is not a major success

factor. As previously, the major factor appears to be a metropolitan location, as seen for example in the cases of Manchester and Birmingham.

Table 4.5: Distance between specialised and non-specialised STPs

STP specialised in pharmaceutical/biomedical research: Name	Distance (km) to the nearest pharma specialised STP	Distance (km) to the nearest STP (all of UKSPA)
Imperial College Incubator	33.95	0.47
Birmingham Research Park	21.4	4.35
Manchester Science Partnerships	49.3	5.68
Cambridge Biomedical Campus	6.53	6.89
Cambridge Science Park	6.53	0.46
Liverpool Science Park	37.42	0.26
Cardiff Medicentre	42.98	1.45
BioCity Group Ltd	19.62	3.09
Sussex Innovation Centre	73.14	55.91
Wellcome Genome Campus	4.32	5
Oxford Science Park	4.08	4.42
University of Glasgow - Clinical Innovation Zone	3.67	14.94
Chesterford Research Park	4.32	6.67
Oxford BioEscalator	4.1	1.23
University of Wolverhampton Science Park	21.58	20.76
West of Scotland Science Park	3.67	18.6
Charnwood Campus	19.62	3.03
Milton Park	11.83	4.36
Edinburgh Technopole	67.75	0.73
RoCRE	13.5	10.83
Stevenage Bioscience Catalyst	13.5	9.77
Unit DX	42.98	0.71
Hethel Innovation	82.78	8.03
Lincoln Science and Innovation Park	49.71	45.11
Porton Science Park	61.39	28.81
The OpTIC Technology Centre	37.42	37.42
Wilton Centre	144.56	24.95

Table 4.5 shows that only the Wilton Centre was an outlier in being unusually isolated from other STPs. Table 4.5 also shows that STPs can be relatively close to each other (12.00 km, SD 14.72) if the STPs do not share the same speciality. STP sharing specialisation in pharmaceuticals was much further apart, average 32.65 km (SD 32.58). To see if the difference

in these separations is statistically significant, the data were analysed in Stata, and the results are shown in table 4.6.

Table 4.6: Statistical analysis of the results from table 4.5

	Regression Statistics
Multiple R	0.391141678
R Square	0.152991812
Adjusted R Square	0.119111485
Standard Error	13.81750761
Observations	27

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	862.1444039	862.1444039	4.51565328	0.043648843
Residual	25	4773.087915	190.9235166		
Total	26	5635.232319			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.00%*	*Upper 95.00%*
Intercept	6.226129632	3.800958184	1.63842128	0.113939661	-1.60290284	14.05434955	-1.60290284	14.05434955
Distance to the nearest pharma-specialized STP (from table 4.1)	0.176741904	0.0831724	2.1256654	0.043648843	0.005445139	0.34838669	0.005445139	0.34838669

These results (Table 4.6) show that there is a significant difference between the distance from one pharma-specialised STP to the next, and the distances between pharma-specialised STPs and other STPs (p-value = 0.0436).

4.4 Conclusion

The mapping of UK firms resulted in 1138 out of 1717 firms (approximately 67%) specialising in pharmaceutics being identified in potential "catchment areas" of either pharmaoriented STPs or UoA3 universities. However, there may be an imbalance between firms self-identifying with SIC codes 21100 (Manufacture of Basic Pharmaceutical Products) and SIC code 21200 (Manufacture of Pharmaceutical Preparations), with universities that self-return in UoA3 (Allied Health Professions and Pharmacy). Table 4.1 indicates that, on average, 19.15 firms with a similar specialisation are present in the locality surrounding a specialised STP, which may suggest that this is the necessary number of firms for knowledge spillovers (Mellor, 2015) to start to occur. It should be noted that there are STPs with more firms, which may be due to their location in metropolitan areas where there are simply more businesses present. This may be a weakness in the methodology, as counting the number of firms works well in rural settings (Kussainov et al., 2020) but may introduce artefacts in metropolitan settings where 200 square km can represent the area of a medium-sized city. This artefact would still be present if time distances were used instead of Euclidean distances. In this study, actual (Euclidean) distances are used instead of time distances, as the small areas being considered; even at a maximum of 7.89 km, the "time distance" may be up to 15 minutes, which is not considered burdensome, and is also negligible in terms of "cost distance".

Conversely, the presence of two prominent non-metropolitan locations, Oxford and Cambridge, which boast several well-established and highly successful STPs, has garnered significant attention. These two locations have evolved into self-sufficient ecosystems characterised by spinouts, mergers, and serial entrepreneurship (Mellor, 2019). However, it is important to note that the associated universities chose not to return to UoA3, which was a matter of their own internal policy decisions. Nevertheless, the situation in these mature and large STPs has limited relevance to new and emerging STPs, which is the focus of this study.

As with firms around universities, the findings are similar to those for firms around STPs; an average of 43.77 per university. When the metropolitan effect is discounted, then there is little evidence that high-ranking universities can attract specialised NTBFs. To investigate this further, on-campus (within 2 km of the university) STPs were selected and analysed, and the results show they are not significantly different from other STPs (table 4.4), underlining again that a close geographical association between an STP and a university is not a major success factor. This again supports the results presented by previous authors, that found that co-operation between businesses and universities demand very narrow asset specificity (Johnston, 2019; Johnston, 2020), which is often not fulfilled. Johnston et al. (2021) found that higher levels of licensing income and patents for UK universities are associated with higher levels of research income in priority technologies, whereas Will and Mellor (2019) surveyed EU countries using large panel data sets, finding no correlation between university research funding and entrepreneurial outcomes, although the work of Will and Mellor (2019) did not focus specifically on priority technologies. Thus, the work presented here and elsewhere (e.g., Perkmann et al., 2013; Winters and Stam, 2007) tends to conclude that, generally speaking, there are no compelling reasons why NTBFs, as inhabitants of STPs or not, would need to co-locate around universities; as D'Este et al. (2013, p357) put it *"... when firms located in dense clusters engage in collaborative research with universities, they do so essentially independently of the university's location..."* and an example of collaboration could be with cutting-edge priority technology, but in times dominated by e.g. Microsoft Teams and Zoom, the university does not have to be nearby. This obviously has knock-on effects for regional development.

STPs are amongst the favourite choices in the policymakers arsenal when it comes to regional economic development (for a recent review, see Amoroso et al., 2019) and the importance of technology and business clusters (STPs etc.) in strategies of regional development is well acknowledged, unfortunately it is also becoming clear that the majority of these initiatives fail to grow; both globally and in the UK, only about ~20% of STPs are successful (Wadhwa, 2013; Kelly and Firestone, 2016; Pugh et al., 2018). Part of the problem may be that basic metrics like how close together clusters can be to each other are unknown, as is how they compete with each other in their ecology. Indeed, many regions - fearing downturn - want to stimulate innovation by founding even more STPs etc., but this may simply lead to an overcrowded landscape, disappointing failures and even more resources wasted.

In the UK, STPs that are part of the UKSPA exist in an idealised landscape on average 12 km apart (SD 14.72 km), as shown in table 4.5. STPs specialised in pharmaceuticals were much further apart, average 32.65 km (SD 32.58 km), and this difference is highly statistically significant (table 4.6). This result appears to support the finding of Albahari (2019) that differing specialisations can be a key to understanding the effects of STPs in a landscape. This result represents, to our knowledge, the first time that geospatial measurements have yielded concrete results in the area of STP spacing and regional development. Nevertheless, in real life more complications may exist e.g., that a new STP may be over 33 km from an established STP, but the NTBFs may prefer to inhabit the older STP when it is more prestigious. Or vice versa; older STPs may be full to capacity, allowing new overflow STPs to be located closer.

In summary, our initial hypothesis on the formation and development of STPs is taking shape, and we are beginning to grasp how to establish thriving clusters from scratch, in order to compete and inhabit a real landscape. The findings presented here emphasise that major metropolitan areas are definitely inhabited, but their universities are not major factors for firms and STPs to co-locate to them. Indeed, D'Este et al., (2013) speculate that travel nodes may be a larger attraction. Non- or differently- specialised STPs can exist at around 12 km distance to each other in the UK. However, to capitalise on the larger economic returns derived from high-tech specialisation, a larger distance of >32-33 km appears to be required. Having >20 firms with the same speciality as the STP within 7.89 km could also be advantageous. After being established, Al-Kfairy et al. (2019a) and Al-Kfairy and Mellor (2020), using a transaction cost perspective, show that STPs start very simply and grow. To avoid "lock-in" with old technology, STPs need a regular influx of innovative firms with new ideas (see Cadorin et al., 2019; Mellor, 2015) and STPs can best manage the trade-off between being parsimoniously innovative or potentially overwhelmed by "bad-fit" innovations, by attracting help with decision-making. Successful STPs appear to achieve this by being a hotbed of innovation and using this in attracting larger firms (Al-Kfairy et al., 2020; Mondal and Mellor, 2021) within a 20-year time frame. These larger firms are needed to reenforce good decision-making. Two larger firms in an STP improves the quality of decision-making dramatically, although involving more than two increases the transaction costs while adding only marginally to the quality of decisions. This ambidextrous situation (Will et al., 2019) was found to be superior under all circumstances (Al-Kfairy et al., 2020). Failure to follow this trajectory may well result in market failure or involuntary business re-orientation to lower technology levels (Mondal and Mellor, 2021). On-cluster firms grow to around seventeen years old and to size around 130 employees (Al-Kfairy et al., 2019a), then either level out as growth stops, or the firm in question leaves the STP (Al-Kfairy and Mellor, 2020), which could be for several reasons, including the demand for larger physical space, etc. The Covid pandemic changed the world of work and hybrid, both physical and virtual collaborations between firms and other inhabitants, as well as the Park CI, offer distinct advantages and challenges. Physical collaboration is generally more significant for most firms within STPs, particularly those in industries requiring access to physical resources, hands-on innovation and in-person relationships. While virtual collaboration offers other advantages and indeed it frequently serves as a complement to, rather than a substitute for, the tangible benefits of physical proximity within an STP. As Kussainov et al. (2020) point out, entrepreneurs need to be not far from "the buzz".

Contribution of the Chapter

This study enhances our understanding of the structural requirements for developing effective Science and Technology Parks (STPs) in the pharmaceutical sector, focusing on key spatial and economic factors. It emphasizes the importance of achieving a critical mass of specialized firms within a ~7.89 km radius for effective knowledge spillovers, while noting that university proximity is less critical to STP success. Additionally, the research identifies an optimal distance of over 32 km between specialized STPs to minimize competition and support regional innovation hubs. These findings contribute to the broader discourse on regional economic development and the Triple-Helix model, highlighting the need for strategic spatial planning to balance collaboration and competition in STP ecosystems.

5 Developing young Science and Technology Parks: recent findings from industrial nations using the data-driven approach

5.1 Introduction

Lim et al. (2022) carried out an extensive examination of science and technology parks (STPs), delving into the potential of enhanced public infrastructure to drive sustainable progress. These advancements extended beyond environmental quality, encompassing the creation of superior working environments and fostering thriving business ecosystems. However, several paradoxes arise upon further exploration of STPs. Initially, the development of STPs is often viewed as a strategic move to spark the emergence of a 'knowledge economy.' This vision is particularly attractive for regions lacking robust economic frameworks. For regions with weak economic structures, the prospect of an STP contributing significantly to local economic growth and promoting regional development is highly attractive. This expectation has been supported by various studies and reviews (e.g. Cadorin et al. (2019); Leitão et al. (2022), which present recent reviews). Despite optimistic projections and substantial state support typically accompanying the establishment of STPs, the reality is that only about 20% of these parks achieve sustainable success. This statistic is substantiated by global studies (e.g. Wadhwa (2013); Kelly and Firestone (2016) for global figures and Pugh et al. (2018) for the UK).

This question is important with respect to sustainability in regions as well as sustainability in the entrepreneurial ecosystem: especially in times of recession, regions will be eager to establish more STPs, and unfortunate this could be the wrong direction to take, not only leading to non-viable STPs being established and squandering resources, but also possibly diluting the impact (and thus the viability) of those nearby STPs that are only borderline successes. This report does not purport to be a review of STP research generally, nor does it touch on large 'top down' structures, implemented on a grand scale, but rather on STPs that have started small and grow sustainably with their clients and who understandably wish to identify their stages and goals. Like all such studies, it has its drawbacks, most obviously that as always data from bankrupt and otherwise 'unsuccessful' instances are not available. Nonetheless, it presents an up-to-date statistical 'state of play' of use to both academics as well as practitioners from STPs and regional planning, as well as to tech entrepreneurs pondering over how to select an STP for their firm to sustainably inhabit. Thus, we aim to acquaint the reader with results from recent data-driven and econometric analyses concerning the performance indicators of start-up STPs and their start-up inhabitants in industrialised countries. Historically, the management and enterprise development of technological products, services, and companies are important and perennial themes, and the management of emerging technologies often involves curated locations, using many different terms, including incubators, catapults, STPs, etc.

Modern ‘tech entrepreneurship’ began approximately in the final quarter of the previous century, when high-tech start-ups were classically formed (“spun-out”) from university research labs, attracted early-stage funding from different kinds of venture funding and migrated out of the university to young, new STPs, in turn being sponsored by government initiatives. These STP-inhabiting (on-cluster/on-STP) firms then found more backers and finance and, in turn, needed more input from university research labs, thus roughly representing the corkscrew motion of the three sectors around each other; the classical triple helix. This view has undoubtedly become much more complicated, as pointed out by Germain et al. (2022).

The major theory behind the concept of STPs is the triple helix, Leydesdorff and Etzkowitz (2002), which led to the present model of STP development Ketels (2017). Recently the “Triple-Helix” model was criticised by Galvao et al. (2019) as being too imprecise for use in regional planning. Authors such as Perkmann et al. (2013), using the statistical analyses of large datasets, revealed that it is very difficult for universities to attract research contracts from businesses. In agreement with this, Winters and Stam (2007) showed that even where such relationships are built, they are often devoid of new innovations. Furthermore, some of the newer results presented here are also at variance with the classical view of ‘Triple-Helix’ development (Etzkowitz and Leydesdorff, 2000), and it is suggested that recent effects of decentralising technologies are decoupling the strands of the helix over time.

Because of the rather opaque backdrop, we decided a decade ago to adopt a clear data-driven approach. This approach involves two new concepts; firstly Mellor (2019) and Will et al. (2019) showed that innovations can have a negative value. Secondly, as proposed by Nobel laureate Joseph Stiglitz, the organisational architecture determines corporate performance. Such parameters allow researchers to use econometric tools such as structural equation modelling (SEM) and Markov chain Monte Carlo (MCMC) techniques (Al-Kfairy, 2021), often in conjunction with big data (e.g., Mellor, 2018), panel data (e.g., Al-Kfairy et al., 2020) and Geographic Information System (GIS). GIS has been used for studies on STPs by Kussainov et al., 2020 and by Mondal et al., 2021. Other allied approaches including a hybrid MCDM analysis (Lim et al., 2022) have also been reported.

5.2 A theoretical base

According to the innovation-based theory of the firm (Mellor, 2015 and Costello, 2019), young new firms seeking to inhabit STPs can be regarded as being (possibly solo) innovations, merely wrapped into an incorporated state. As shown in figure 5.1, allowing a good-fit firm to inhabit an STP results in benefits, while a poor-fit candidate would result in losses. Thus, at an early stage, young STPs encounter a decision-making tree in which decisions about which innovative new firm (seen as a potentially incoming innovation) is allowed to join the STP cluster begin in an ad hoc fashion, but due to the small scale, mistakes at this stage are not very costly.

5.2.1 Critique of STPs role in the regional economy

Using the UK pharmaceutical industry as an illustrative example, Mondal et al. (2020) emphasised the importance of a local population of over 20 specialised firms in supporting a nascent Science and Technology Park (STP). This critical mass of specialised firms creates a robust ecosystem that fosters innovation and collaboration, which are essential for the success of start-up STPs. Additionally, the study highlights the importance of spatial considerations, suggesting that specialised STPs require a minimum distance of over 33 km from their nearest competitor to avoid market saturation and maintain a competitive advantage. However, these specialised STPs can be situated as close as 12 km from non-specialised STPs without facing direct competition, allowing for a diverse and complementary regional innovation landscape.

Kussainov et al. (2020) conducted an empirical examination of firm density near several UK Science and Technology Parks (STPs). Their study uncovered clear spatial patterns for IT-specialising and biotech-specialising STPs and firms. In particular, they observed that firms in these sectors tend to cluster in an annular ring situated approximately 4 to 7 km from the STP. This arrangement appears to be a strategic spatial configuration in which firms profit from proximity to the STP, gaining access to resources, talent, and collaborative opportunities while still maintaining a sufficient distance to alleviate issues related to congestion and resource competition in the immediate vicinity of the STP.

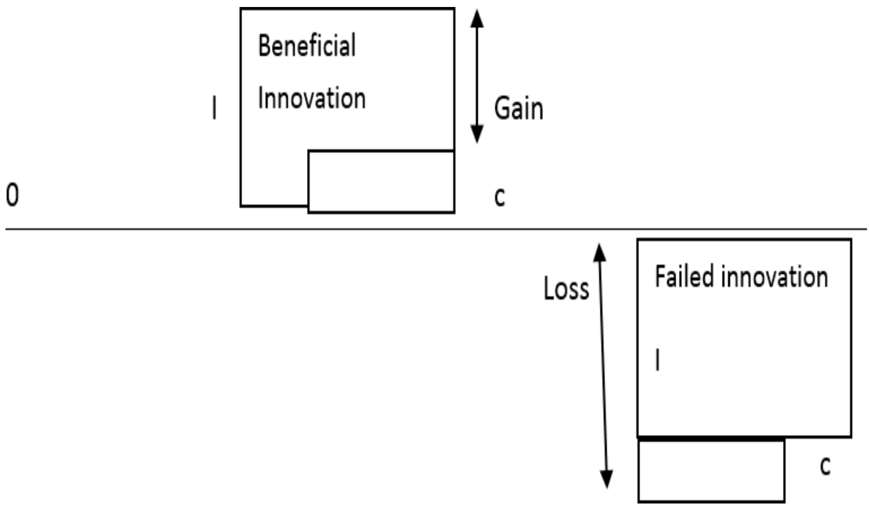


Figure 5.1: Effects of adopting good-fit and poor-fit innovations.

The financial effects of a beneficial innovation (“Gain”) is ‘I’ minus ‘c’, where ‘I’ represents the value of the innovation and ‘c’ represents the costs of implementing the innovation. This can be represented by [I minus c]. If the innovation is poor-fit, the loss is [minus (I plus c)], and is a larger amount than “Gain” (taken from Mellor, 2019).

According to Mondal et al. (2021), high-scoring universities in pharmaceutical sciences in the UK do not necessarily attract pharmaceutical science-focused firms or specialised technology-transfer platforms (STPs) to their locality. This finding challenges the notion that academic excellence in a specific field automatically leads to clustering of related industrial activities. Additionally, this study found that on-campus STPs do not have a significant advantage over off-campus STPs in attracting firms specialising in pharmaceutical sciences, suggesting that proximity to academic institutions alone may not be a decisive factor for these firms when choosing their locations.

Two recent studies investigated the broader entrepreneurial impact stemming from academic institutions. Vanino et al. (2019) analysed research grants using the UK Gateway to Research database and found a positive correlation between grant funding and entrepreneurial activities. However, another study (Will and Mellor, 2019) that surveyed EU countries using extensive panel datasets found no significant correlations. This discrepancy may highlight some limitations inherent in "Big Data" methodologies.

Johnston (2022) and Audretsch and Belitski (2022) emphasised that university-industry co-operation is influenced by a range of factors, including social, technological, and organisational proximities, which are often not captured in large-scale data analyses. Radko et al. (2022) further emphasised the importance of organisational structures across different stages of entrepreneurship and the varying profiles of universities. It is clear that a better understanding of micro-level practices is needed, and although this is not the intent of the present authors, it may be that the conflict in findings between Vanino et al. (2019) and Will and Mellor (2019) demonstrates that "Big Data" approaches are too coarse-grained and that case studies, as communicated by Radko et al. (2022), on successful technology transfer departments will reveal more.

The outcomes presented herein ought to be considered when incorporating Science and Technology Parks (STPs) into regional development strategies; it is evident that high-tech STPs hold greater value for the nation than basic business clusters (Albahari et al., 2018). Although simple business clusters may occasionally prove beneficial, the aforementioned criteria should help planners manage their expectations effectively.

5.2.2 Critique of the Triple Helix

Al-Maadeed and Weerakkody (2016) emphasised that the 'classical' triple helix theory (Leydesdorff and Etzkowitz, 2002) posits a knowledge-based economy as the driving force behind scientific and technological innovation, which, in turn, generates national economic wealth. However, this theory does not adequately address the sequence in which the functions of the triple helix - universities, industry, and government are initiated and interact in practical applications. The conventional model assumes a linear progression, usually beginning with university-generated knowledge, leading to industrial applications and subsequent governmental support. In practical applications, the initiation points and interactions among triple helix components can vary significantly, often challenging the classical model. For instance, the rapid development and deployment of COVID-19 vaccines by New Technology-Based Firms (NTBFs), such as BioNTech and Pfizer, exemplify a scenario where industry-led initiatives, supported by governmental facilitation, preceded extensive academic involvement. Conversely, ventures such as SpaceX represent industry-driven innovation that, while benefiting from academic research, primarily advances through private sector dynamism and government partnerships. These examples demonstrate the inadequacies of the classical triple helix model in accommodating the diverse and nonlinear pathways of innovation and economic development. This variable initiation point complicates the traditional perspective of Science and Technology Park (STP) development, which often envisions a process starting with university spin-outs or high-tech firms and subsequently seeking additional intellectual input from academic institutions. Another critical aspect of triple helix theory is the role of graduate recruitment, which is often complicated by the high mobility of graduates. This mobility can disrupt the continuity and stability expected in the classical model, where the local retention of talent is assumed to support ongoing collaboration and innovation within the STP ecosystem.

To this, one must now add that:

a. A poor-fit innovation (e.g., accepting an innovative firm that does not fit well into the STP specialist area) may give rise to a negative outcome (Mellor, 2019; Will et al., 2019).
b. Intellectual input into university-business co-operation is infrequent due to narrow asset specificity, as reported by (Johnston and Huggins, 2018; Johnston, 2019; Johnston, 2020).
c. Post COVID-19 appreciation of new sets of technology means that firms can make a move from STP premises to adjoining locales (Kussainov et al., 2020), reaping advantages such as cheaper locations while experiencing minimal disadvantages.

The sum of the above factors imply that the classical model of STP development (see, e.g., Ketels, 2017), may well need updating.

5.3 STP Development

5.3.1 Early Stages

STPs that have started small and grow with their clients typically contain a central cluster initiative (CI) connected to single gatekeepers in each on-cluster/on-STP firm, giving structure to what may well be an adhocracy with a "star" topology. This topology is optimal for keeping transaction costs low (Al-Kfairy et al., 2020; Al-Kfairy et al., 2017). At this stage, as with all stages, micro firms with 3, 2, 1 or zero employees (in the latter case, the founders probably retained their other jobs) can join the STP and they typically either grow or disappear within a maximum timeframe of 5 years (Al-Kfairy et al., 2017).

As an STP grows, poor decisions will inevitably become more and more costly, and to avoid a market failure (see Figure 5.2) may force a high-tech STP to re-focus into a lower-tech area, e.g., hosting general businesses, incubator services, etc. (Al-Kfairy and Mellor, 2020). The alternative route, the other branch of the 'Y-shaped path', is where decision-making can be strengthened within 20 years of STP founding, by including experienced managers from larger firms who possess relevant in-depth knowledge (Mellor, 2021). To do this, the young STP should become a focus of innovation that can attract larger firms interested in new ideas, fresh talent and takeovers (Wegner and Mozzato, 2019). There is a trade-off between improved decision-making and the transaction costs incurred for the improvement, which occurs when decision-makers from two large organisations are included in the process (Al-Kfairy and Mellor, 2020); although more than two large firms may be present in the STP, involving more large firms simply increases the transaction costs. This scenario was checked by (Mondal and Mellor, 2021), who compared STPs with zero or two large firms in residence, finding support in that the employment rates amongst on-cluster firms in the STP when two large firms were present were significantly better than in the case when no large firms were present, using off-cluster employment as a control (Mondal and Mellor, 2021).

Figure 5.2 indicates that the potential benefit and loss for STPs in the early stage are modest. Indeed, generally speaking, the cost of poor management is not onerous (Mellor, 2016). Even with 400 on-cluster firms, Figure 5.2A shows around 20,000 MUs of benefit or loss. At this stage, the innovation output for on-STP firms is not related to R&D expenditure, but rather to networking, as expressed by social expenditure (Al-Kfairy et al., 2018; Al-Kfairy et al., 2019b). The work of (Al-Kfairy et al., 2019b) showed surprisingly that innovation in on-STP firms depended on spending over 15% of their turnover on organising social events, networking, partnership, etc., with other on-STP firms, and that this was found during all stages of STP growth.

At this stage, STPs should be a veritable hotbed of innovation, attracting the attention of larger firms who, in turn, are interested in acquiring new innovation(s), headhunting new talent and buying up young firms by means of Mergers and Acquisitions, etc. (Cadorin et al., 2019).

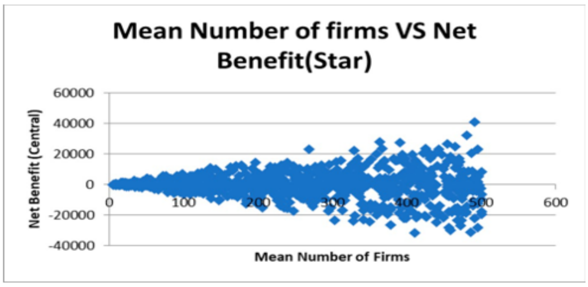
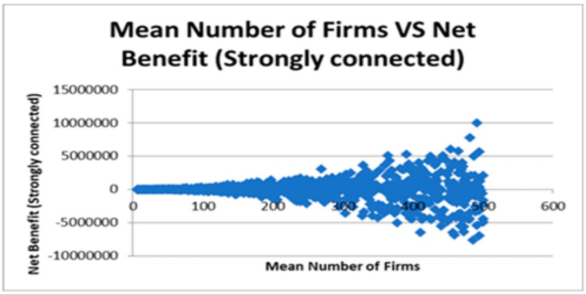
Stage	SEM	Plot
A: Early Stage STP, "Star" topology	$\pi=\sum_{j=2}^{N}(B_{1,j}-C_{1,j}),$	
B: Late Stage STP including ambidextrous connections between on-STP firms	$\pi=\sum_{i=1,j=1}^{N}(B_{i,j}-C_{i,j})$	

Figure 5.2: Monte Carlo scatter plots obtained using structural equation modelling (SEM) and the respective formulae given in the column marked “SEM”. On the abscissa (x) axis represents growth (number of firms in the STP) increases. The ordinate (y) axis refers to net benefit or loss in monetary units (MUs, standardised measures of financial value). The data were recalculated from those presented by Al-Kfairy et al. (2020) using Matlab 2018R and a cellular automata approach.

5.3.2 Mid Stage

The data presented in Figure 5.2B indicate a substantial boost in productivity when shifting from an initial-stage topology to a successful ambidextrous topology in the STP. There is a substantial difference between the outcome of a simple topology, which yields approximately 20,000 MU at 400 on the abscissa, and an ambidextrous topology, which yields approximately 5,000,000 MU. However, as Stiglitz's theory predicts, this transition must be managed carefully, as unsuccessful transitions can result in significant losses of approximately 6,000,000 MU. For STPs, it is essential to continually invite innovative firms that employ new technology and ideas to prevent 'lock-in' with old technology firms. The decision on how to choose incoming client firms is critical, as a suboptimal choice could lead to rapid failure, which could harm the taxpayer and the firms that correctly chose to inhabit the STP. Al-Kfairy et al. (2020) found that involving experienced decision-makers from two large firms is the tipping point for the CI to choose the best-fit incoming inhabitants within 20 years. However, involving more than two large firms does not significantly improve decision-making but increases transaction costs exponentially. The transition from an initial star topology to an ambidextrous topology enhances the knowledge spillover, which is vital for stimulating innovation. Several studies, such as (Bell, 2005; Squicciarini, 2008; Dettwiler et al., 2006), have reported that networking within business clusters stimulates innovation to levels higher than those found in isolated SMEs.

At this stage, the number of off-cluster firms surpasses that of the on-cluster firms. The innovation produced by off-cluster firms appears to bear a minimal connection with R&D expenditure but not with networking (social) expenditure (Al-Kfairy and Mellor, 2020). A concise representation of this is presented in Table 5.1.

Table 5.1: A summary of factors leading to the success of off-cluster firms and showing that on-STP success factors are more stable. Taken from Al-Kfairy and Mellor, 2020.

Factor Examined	On Cluster	Off Cluster
Shareholders' investment	Positive linear (effecting employment growth)	Positive linear (effecting employment growth), negative linear for innovation capabilities.
Firms' age	Quadratic (effecting employment growth), quadratic (effecting financial growth)	Positive linear (effecting firms' employment growth), negative linear (effecting financial growth).
Firms' sizes	Quadratic (effecting financial growth)	Quadratic (effecting financial growth)
Innovation capabilities	Positive linear (effecting employment and financial growth)	NA
Social Expenses	Positive linear (effecting innovation capabilities)	Negative linear (effecting firms employment growth), negative linear (effecting innovation capabilities)
ln(R&D)	Positive linear (effecting financial growth)	Positive linear (effecting financial growth).
R&D	NA	Negative linear (effecting innovation capabilities)

To form an overview of the three stages, data were recovered from (Mondal and Mellor, 2021) and (Al-Kfairy et al., 2019b) and recalculated, and the results are presented in Table 5.2.

Table 5.2: Comparison of three Swedish STPs at the three growth stages.

STP	Number of Large Firms on-Cluster	Average Growth Rate (2013–15 Inclusive) as Number of on-Cluster Employees	Growth Trend (as of 2018)	Percent of Total Municipal Employment
Umeå Science Park	0	34%	Declining	0.10%
Skövde Science Park	2	19%	Rising	0.55%
Linköping (Mjärdevi) Science Park	4	~0%	Flat	1.00%

As depicted in Table 5.2, the mature and well-established Science and Technology Park (STP) contributes a substantial portion of the regional employment, although at present, the growth in the number of employees within the STP remains stagnant, likely due to the phenomenon of 'churn', which refers to an equilibrium between the number of employees graduating and those leaving the STP to be replaced by newcomers. In contrast, the employment landscape of the mid-stage STP, wherein decisional support is bolstered by the presence of two large firms within the cluster, is significant and on the rise, resulting in over half a percent of regional employment being tied to the STP. Conversely, the early-stage STP lacks the support of large firms, and while its growth rate in on-STP employment appears promising, this may be attributed to the relatively small numbers involved, given that this particular STP is responsible for only 0.1% of regional employment (Al-Kfairy et al., 2019b).

5.5.3 Maturity

Clearly, it is subjective to determine the point at which a Science and Technology Park (STP) is considered "mature." However, taking into account the successes of certain STPs (e.g., Kista, WISTA, Research Triangle Park, Sophia Antipolis, Mjärdevi, Cambridge and Oxford STPs), one could argue that an STP that has been in operation for over 30 years could be considered mature. Such large mature STPs are the ‘rock stars’ (Mondal et al., 2021) of the tech entrepreneurship ecosystem, although they can have their ups and downs (see Stam and Martin, 2011). They are comprised of a self-sustaining community of new and seasoned tech entrepreneurs who are well-connected to one another and to venture capital (as outlined in (Mellor, 2019)). The decision-making process within these STPs is well-supported, as many of the inhabitants are large firms. Additionally, universities often find this stage of an STP's development to be the most appealing.

In mature STPs, on-cluster firms either plateau out (both financially and in terms of employment) at ~120–150 employees after 15–17 years, or they leave the STP. Those that stay may have reached the limits of the owners’ ambition and apply a ‘capped growth’ (Mellor, 2011) scenario because at all stages, on-STP firms are, on average, more protected against external economic shocks (Al-Kfairy and Mellor, 2020; Yang, 2022) than off-cluster firms, meaning that the owner may be in a comfortable position to wait for, e.g., a market shakeout, as recently found for French high-tech firms (Gharbi and Othmani, 2022) and substantially confirmed using GARCH models (Lin, 2022) and also by using wider economic indicators (Yang, 2022).

Conversely, inhabitants can leave the STP; they may be heading for an IPO (in business terms), or, in physical terms, they may need larger premisses, and obviously there may be other reasons (see, e.g., Al-Kfairy et al., 2022). Indeed, Crescenzi et al. (2016) indicated that geographical proximity is only weakly correlated with efficacy in external networks. Interestingly, more recent preliminary results presented by Kussainov et al. (2020) imply that when firms leave the STP, they may not move far away. Kussainov et al. (2020) measured firm density around several UK STPs and found that for IT-specialising STPs and firms, as well as biotech-specialising STPs and firms, the firms formed an annular ring measuring 4-7 km around the STP.

Traditionally, biotech and medical firms tend to cluster together in order to share expensive facilities such as a bio-hazard waste incinerator and the storage of dangerous chemicals (Rowe, 2014). However, there is a growing concept that firms move away from STPs by using IT and network technologies, resulting in a wider choice regarding premises that are better to inhabit. The use of IT may not only be limited to IT firms; the emergence of small-scale cheap technologies around, e.g., the incineration of bio-waste (see, e.g., Neri et al., 2018) may well be reducing the reliance of off-cluster biotech firms on centralised large facilities. This concept is supported by results from open markets (Nikiforou et al., 2020) which found that technological networks are more beneficial than physical close associations, and indeed the results presented by Howells and Bessant (2012) reinforce this, showing off-cluster firms diffusing outward to a distance of up to ~8 km, a figure in good agreement with Kussainov et al. (2020). These distances are within easy travel range, thus theoretically enabling off-cluster tech entrepreneurs to have the luxury of choosing more suitable premises while still being close enough to the STP ‘buzz’ to be able to attend when events, etc., take place.

5.4 A New Model?

Despite the criticisms typically levelled in life cycle models, (Ketels, 2017; Martin and Sunley, 2011) have developed a life cycle model for Science and Technology Parks (STPs). Figure 5.3 depicts a comparable model derived from the data-driven analysis presented herein.

As illustrated in Figure 5.3, micro-firms usually leave the STP within five years or grow into larger firms within the STP. The STP necessitates a continuous inflow of new innovations and attracting two or more large firms within 20 years enables the CI to make better decisions. Without this, the STP may experience stagnation or return to a low-innovation park. Firms may depart from the STP once they reach approximately 120 employees, with some of these firms relocating to an annular ring 4-7 km away. As the STP grows and becomes fully functional, successful tech entrepreneurs may transition to serial entrepreneurs or business angels, providing support to small firms in their early stages (Mellor, 2008).

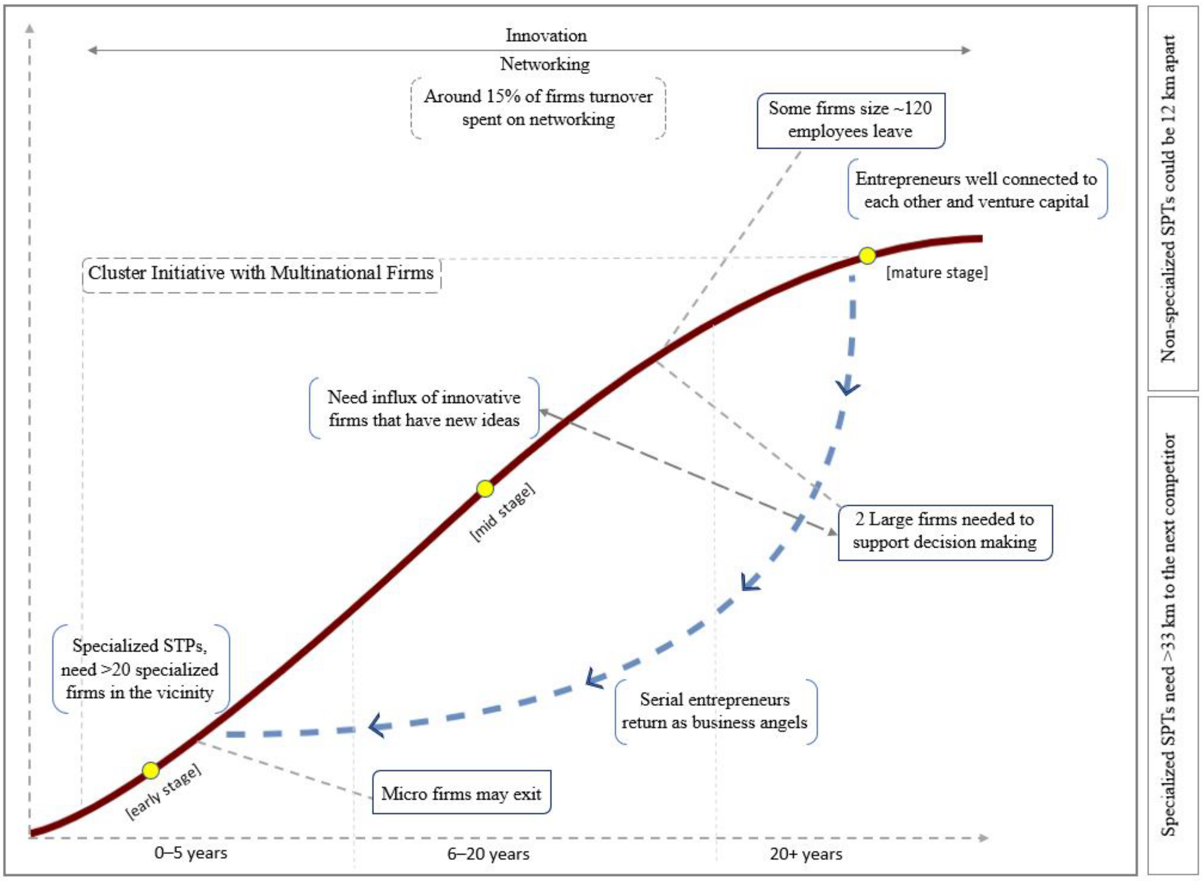


Figure 5.3: STP Life Cycle Model - A Graphical Overview of the Findings (Author's own model)

How do STPs and potential inhabitant firms find each other? Science and Technology Parks (STPs) can employ some general criteria to select tenants who are likely to contribute to the park's success. These criteria include alignment with the park's mission, innovation potential, collaboration capacity, scalability, and financial viability. However, as Mondal and Mellor (2021) point out, the Park CI is unlikely to have deep insight into specialized technical matters and thus large enterprises within the park can play a pivotal role in this process by identifying promising start-ups and SMEs that align with their industry focus and technological requirements. Conversely the "road map" developed by Mondal et al. (2023) gives broad pointers to entrepreneurs as to which STP to choose.

5.5 Future directions

Several future scenarios for STPs have been formulated (see, e.g., Makhdoom et al., 2022) and we hope that the findings reported on here will be of use to tech entrepreneurs, either as leaders of SMEs involved in developing new and sustainable products, or involved in steering STPs. The data-driven approach strives to be numerical and put statistically valid measures in place. Clearly, there will be occasions where the figures cited will not be representative because they have been gleaned from well-populated states with an advanced industrial base and may thus not be applicable to all countries. Nevertheless, the model shown in Figure 5.3 may still act as a guide.

Additionally notable are the indications that the triple helix model is evolving, and the recent effect of decentralising technologies on tech entrepreneurship, business generally and management and enterprise development in particular is to loosen the interconnection between the strands of the helix and consequently that the triple helix model may need updating, taking new and more sustainable working practices into account.

5.6 Conclusions

Nobel laureate Paul Romer emphasised the importance of technological innovation, arguing that market economies may not generate sufficient new ideas. Therefore, "*well-designed government actions*" (Nobelprize.org, 2018) are necessary to stimulate innovation, such as providing subsidies for research and development, funding research at universities, and establishing STPs. For instance, it is unclear which measures are most effective in supporting the national expenditure of a country to underpin its national industrial strategy. There is also a research gap regarding the relationship between stakeholders, including research councils, the state, regional/local government, the STI organisation itself and its associated organisations, and client firms, as well as how external (off-cluster) firms and local associations (Chamber of Commerce, etc.) contribute due to the lack of clear data-driven indicators. The present study aims to address some of these issues.

5.6.1 The Entrepreneurial University

In relation to universities and entrepreneurial motivation, Hegde and Tumlinson (2020) constructed two mathematical models of a probabilistic nature that were mathematically reduced to a nonlinear Bayesian optimisation problem. These models demonstrate that employees who transitioned to entrepreneurship possessed relatively higher abilities than credentials. This finding represents a paradox in the context of traditional university spinouts, in which academics possess good credentials, but low levels of entrepreneurial intent and experience. Furthermore, Panetti and Parmentola (2020) has outlined additional drivers and obstacles in this regard.

We are therefore presented with a series of conflicting paradoxes to be resolved regarding how much of the resources channelled into universities and firms in the UK result in sustainable commercial applications and do STPs (including on-campus STPs) 'capture' this innovation? Certainly, for early and mid-stage STPs, the answer appears to be a clear 'no', a conclusion in agreement with (Perkmann et al., 2013; Winters and Stam, 2007) for a more general discussion, see Tidd et al. (2005), p351–355. Certainly, there are optimistic academic (or student) start-ups grounded on the premises of many universities, but Mondal et al. (2021) shows that on average, on-campus locations are no better than others in attracting serious, specialised, interest from industry. Do successful firms and academics want to spend effort on what may be a 'paper tiger'? Conversely, how many student start-ups can bootstrap themselves? Longitudinal studies following the spirit of Díez-Vial and Montoro-Sánchez (2017) could reveal more detail around these questions.

The work of Johnston and co-workers (Johnston and Huggins, 2018; Johnston, 2019; Johnston, 2020) found that intellectual interactions for new innovations between universities and firms exhibit very narrow asset specificity, and this begs the question: for the 'triple helix' model, does this work best around very large universities because there are simply very many academics, and a small minority of these academics possess the high asset specificity the firm requires?

5.6.2 Sustainability

Sustainability is influenced by various factors such as the relationship between location and population density. According to Pugh et al. (2018), insufficient potential client firms within the area of STPs can result in inadequate performance. Basic indicators such as the level of occupancy (the minimum number of firms required for a viable STP) and turnover/churn rates at different developmental stages remain largely unexplored. However, Mondal et al. (2021) reported that for high-value specialised STPs, at least 20 similarly specialised firms should be present in the surrounding area (approximately 8 km) to support a minimum viable base for the pharmaceutical sector.

Good organisational behaviour is essential in STP management, particularly in the transition from a basic "star" topology to a more intricate ambidextrous topology. Without this, STP will not progress or grow. Even for established and growing STPs, exhibiting the necessary degree of ambidexterity to reduce the tension between collaboration and opportunity as well as conflict and risk may be challenging in a park containing multiple types of organisations (Will and Mellor, 2022). Some authors have also noted this difficulty in achieving ambidexterity, citing specific examples (Ungureanu et al., 2019).

According to Mondal et al. (2021), the distance between STPs in the UK can be as low as 12 km when they are not competing, but the average distance is 33 km when they are competing. Cluster spatial autocorrelation measures can provide more accurate measurements of cluster strength among neighbouring STPs, but obtaining precise data can be challenging in practice (Carroll et al., 2008). Improving the accuracy of the data may require implementing measures such as the Kolmogorov theorem, as suggested by some researchers (e.g. Conway and Smoller, 1986).

5.6.3 The limits of the research

The work presented here regards small young start-up STPs and how to sustainably develop these in regional context, and as such it does not touch on large ‘top down’ structures, implemented by central government on a grand scale. One weakness with the ‘start up’ approach is that data from bankrupt and otherwise ‘unsuccessful’ instances are not available.

Paradoxically, using UK data, Vanino et al. (2019) found entrepreneurial knock-on effects from academia while Will and Mellor (2019) used pre-Brexit EU data, finding no correlation between state support and entrepreneurial outcomes. This may show some limitations to a ‘Big Data’ approach and underlines the validity of using ‘mixed methods’ approaches wherever possible.

Nobel laureate Stiglitz showed that organisational architecture determines corporate performance, and one factor not examined here involves micro-level practices at the organisational structure level of, e.g., technology transfer offices. Indeed, Brescia et al. (2016) initiated studies on successful tech transfer departments.

Contribution of the Chapter

This chapter provides valuable insights into the developmental phases of Science and Technology Parks (STPs) and the dynamics shaping their long-term success. Analysing performance metrics across data-driven STPs, it identifies key factors for sustainable growth, such as firm specialization, innovation alignment, and optimal proximity to other STPs. Challenging conventional Triple Helix assumptions, the findings suggest that STP success often relies more on strategic alignment and management than on proximity to academic institutions, highlighting the unique decision-making landscape young STPs face and the need for adaptable planning and management approaches.

6 Entrepreneurial universities: Modelling the link between innovation producers and innovation users shows that team structures in the tech transfer function improve performance

6.1 Introduction

Nobel laureate Paul Romer (Nobelprize.org, 2018) emphasised the importance of technological innovation, arguing that market economies alone are insufficient in generating new ideas. He posited that "*well-designed government actions*" are necessary to stimulate greater innovation. However, the process by which innovations progress from university laboratories to market economies remains unclear. Etzkowitz (1983) addressed this issue by introducing the concept of "the entrepreneurial university," which was partly based on the case of Stanford University and "Silicone Valley" (see e.g. Adams, 2003). This concept led to the development of the triple-helix model (Etzkowitz and Ranga, 2010), which describes the interdependent relationship between universities, industries, and government bodies. The triple helix model is represented by the corkscrew motion of these three sectors around each other, with the relationship progressing over time. Leydesdorff and Etzkowitz (2002) later expanded the model to include a fourth helix. While the original Triple-Helix model remains the classical model, the relationship between these three sectors has become increasingly complicated, as highlighted by Germain et al. (2022). This study does not aim to review these hypotheses and models, and readers are instead directed to recent overviews by Carayannis and Campbell (2010) and Germain et al. (2022).

Purely functionally, the process (an ‘innovation pipeline’) involves an ambidextrous approach linking research, management, innovation and entrepreneurship (Audretsch and Guerrero, 2023) when transferring innovation from the proposed innovation source, (metaphorically the lab bench or any kind of research performed at a university) to an external recipient. The progress towards commercialisation must first be judged by the university hierarchy to be worthy of an initial investment. Investment includes transaction costs like staff time, patenting costs etc. and a go/no-go decision to be made at high level. As Will et al. (2019) point out, the costs incurred by a failed innovation are greater than the benefits derived from adopting a successful innovation. Thus, a classical or non-entrepreneurial university would be expected to exhibit risk-adverse behaviour including, for example, simply waiving any rights and allowing their employees, the inventors/researchers, to attempt to progress their innovation privately and independently of the university. This type of behaviour from a less entrepreneurial university can indeed be broadly successful for organisations that exist in highly regulated environments (Will et al., 2017). To reduce this option to a user perspective, Hegde and Tumlinson (2020) built a probabilistic model as a nonlinear Bayesian optimisation problem showing that, in universities, academics' credentials are high but entrepreneurial intent and experience tend to be poor. Therefore, research employees transitioning to entrepreneurship may struggle to bring their innovations to the market in the new environment.

On the other hand, the "entrepreneurial" university may choose to invest in the innovation(s) and the necessary surrounding infrastructure, including decision-making, maintaining contact with sources of investment, and the cost of maintaining a Technology Transfer Office (TTO) where the returns are expected to exceed these outlays (as outlined by Harmon et al, 1997). This scenario emphasises the importance of the TTO as an essential link between the knowledge source and the knowledge recipient, a point emphasised by Panetti and Parmentola (2020). In this context, Tracey and Williamson (2023) also recently highlighted this link, reporting that '*Just over half (53%) of respondents had involvement from their TTO when deciding between a spin-out and other commercialisation routes, compared to a third (34%) who did not*'. Once the new innovation has left the university and is embedded in an incorporated entity, either spun out of the university or as a completely separate organisation, as described by Günsel (2015), whereupon that entity may find its place in the high-tech entrepreneurship ecosystem, e.g. a Science and Technology Park (as observed in Germain et al., 2022 and Mondal et al., 2023).

This study aims to identify the most effective practices for transitioning from pure research to a high-technology entrepreneurship ecosystem. The impact of management architecture on corporate performance was first proposed by Nobel laureate Joseph Stiglitz (Sah and Stiglitz, 1986), which has been applied to the high-tech entrepreneurship ecosystem by Al-Kfairy and colleagues (Al-Kfairy et al., 2020, 2019a and 2019b). The research question is: How does the innovation pipeline function best in the space between when innovation leaves the research lab bench and becomes incorporated into the recipient(s)? In the following sections, we simulate the decision-making process in large and small universities and model the outcomes of various management architectures in the essential link department, the TTO. Routine robustness checks and sensitivity analyses were conducted as in Al-Kfairy et al. (2020).

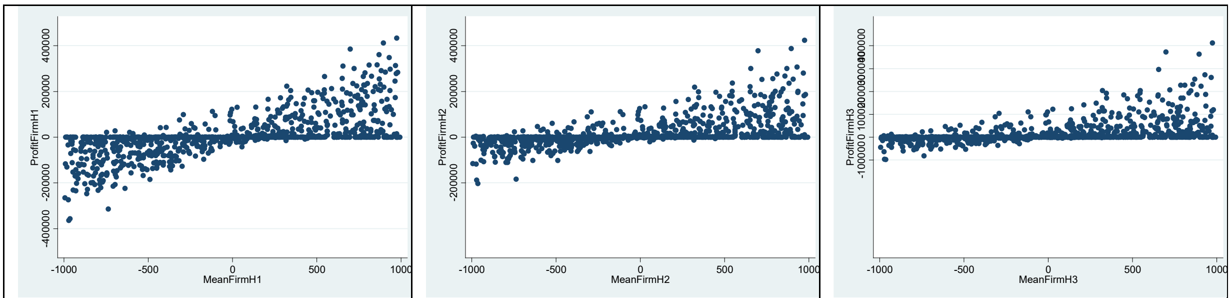
6.2 University decision-making, the effect of size

In this analysis, it is assumed that the inventor or originator of an innovation possesses extensive specialised knowledge and profound technical expertise, regardless of the size and productivity (in terms of innovation) of the university. The initial decision regarding whether to proceed with the innovation is made by a line manager, such as the head of a department or school, dean, or another similar position. These individuals possess less specialised knowledge and expertise than the inventor or originator; however, after making a positive decision, they pass the issue on to their own line manager, who has even less specialised expertise. In simple terms this can be represented by:

$$b = \sum_{i=1}^{n} \begin{cases} b_i, & if\ \rho_i = yes | b_i > 0\ with\ \pi\ or\ if\ b_i < 0\ \ with\ (1-\pi) \\ 0, & if\ \rho_i = no \end{cases}$$

Equation 6.1: Determine quality decision by manager

This equation (6.1) determines the quality of a manager's decision. When the manager accepts good innovation and rejects poor innovation, the probability of making a correct decision, denoted by π, is 0.5 when the manager accepts a good innovation and rejects a poor one. The probability of making an incorrect decision is (1-π). The manager's decision is assumed to be uniformly distributed between 0.5 and 1, representing the difference in quality between a decision made at random (π=0.5) and one made with perfect knowledge (π=1). The outcomes with 1-3 levels of hierarchical decision-making are shown in Figure 6.1 below:



1 level of hierarchical coin-flipping decision-making	2 levels of hierarchical coin-flipping decision-making	3 levels of hierarchical coin-flipping decision-making

Figure 6.1: Comparison of number of levels of hierarchical control for monetary efficiency

The decision-making process typically entails a certain degree of innovation rejection by the hierarchy, which in turn enhances overall performance outcomes by eliminating costly errors. Although improved decision-making skills can positively impact model outcomes, they do not necessarily alter the prevailing trends. For instance, at a small university, the quantity of innovations generated may be considerably lower than that at a larger university. Nevertheless, in both scenarios, the ratio remains consistent; for every additional hierarchy level, the number of innovations is halved, quartered with two hierarchies, reduced to one-eighth with three hierarchies, and so on.

To model the benefit accrued, equation (6.2) can be used. Equation (6.2) calculates the total benefits gained using the gross benefit minus the costs of each connection and where the net benefit for organisation j, will be $B1,j - C1,j$, where j ≠ 1.

$$\pi = \sum_{j=2}^{N} (B_{1,j} - C_{1,j}),$$

Equation 6.2: Monetary Unit advantage observation

The use of equation 6.2 makes it possible to observe the advantage in Monetary Units (MUs) for the number of innovations across any given timescale. The range of innovations examined was between 0 and 500, specifically for large universities. The vertical line in the diagram represents a university that is ten times smaller, with 50 innovations.

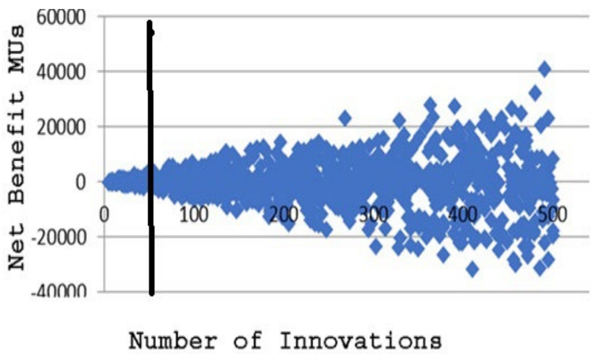


Figure 6.2: Effect of monetary outcomes (in Monetary Units, Mus) with number of innovations showing that with fewer innovations the potential harm is smaller than with larger numbers of innovations, simply because there are fewer opportunities for incurring a damaging loss.

Figure 6.1 presents a paradoxical finding that employing managers with poor decision-making skills is more advantageous than having no hierarchy at all, as it reduces risks. Consequently, to achieve good quality results, managerial decision-making quality must surpass the threshold of merely being better than flipping a coin. This is in contrast to the risk-minimisation approach, in which the university would waive its rights entirely and allow its employees, inventors, to attempt to progress their innovation privately and independently of the university.

Figure 6.2 shows that with increasing size, and thus number of innovations, potential risk and potential benefits also increase. Figure 6.2 contrasts the situation where, after a certain time, we assume a large university produces 500 innovations and a small university only 50. From Figure 6.2 at vertical line 50, it can be seen:

1. Small universities, colleges, etc., have fewer potential gains from technology transfer.
2. Conversely, projected losses are also small.
3. Reduced transaction costs may contribute to the minimisation of losses.
4. Thus, the projected low gains may reinforce the argument against small universities employing a large TTO, with its associated high overheads.

Conversely, it is essential for large universities to prioritise avoiding poor innovations, as the potential losses outweigh the gains in the long term, as demonstrated in Figure 6.2. The Technology Transfer Office (TTO) incurs considerable transaction costs in the context of large universities. Given these circumstances, the hierarchical decision-making structure depicted in Figure 6.1 may not be suitable, necessitating the exploration of alternative structures in the subsequent section.

6.3 The TTO; Different Management Structures

The number of innovations that will successfully navigate the university's decision-making process is likely to be reduced from the initial stage, but the proportion of 'good' to 'poor' ideas may remain unchanged. To enhance the decision-making environment, it is recommended to implement an ambidextrous management architecture within the Technology Transfer Office (TTO). This can be achieved by examining the sustainability of organisational structures for ambidextrous business practices in the TTO and comparing three distinct management configurations: hierarchical, cooperative, and hybrid.

The first model is a hierarchical department known as the TTO. In this model, lower-level employees must obtain approval ρi from the departmental head, and the parameter π assesses the quality of the decision made. The function of this model is equivalent to that in Equation 6.1. As the TTO is a smaller entity than a university, additional hierarchies are unlikely and therefore not modelled.

In the second model (Equation 6.3), the quality of the decision made by cooperating peers is represented by symbol π. Therefore, when staff members perceive the innovation to be beneficial, they need to persuade a larger number of individuals compared to the scenario in which evaluations are carried out by the head of the department (as demonstrated in Equation 6.1). As a result, the overall transaction costs for implementing innovation increase.

$$b = \sum_{i=1}^{n} \begin{cases} b_i - \dfrac{ct}{\pi}, & if\ b_i > 0\ and\ \ b_i - \dfrac{ct}{\pi} > 0\ and\ \dfrac{c}{\pi} < Size\ of\ the\ Organization \\ b_i - \dfrac{ct}{1-\pi}, & if\ b_i < 0\ and\ |b_i| - \dfrac{ct}{1-\pi} > 0\ and\ \dfrac{c}{1-\pi} < Size\ of\ the\ Organization \\ 0, & otherwise \end{cases}$$

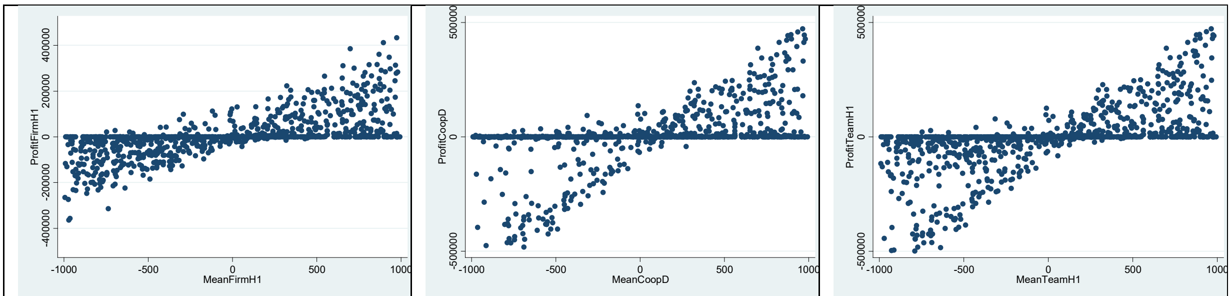
Equation 6.3: Cooperating peers decision quality regression model

The hybrid model is described by Equation (6.4), which outlines the conditions under which staff members utilise hierarchical structures within their organisation. Specifically, the terms *E(hier.)*>E(team) and *E(hier.)*<E(team) represents the relative comparison that staff make between the effects of hierarchy (Equation (6.1)) and the impact of their networks (Equation (6.3)). In instances where the hierarchy is approved by their superiors, and the absolute value through the hierarchy is greater than the effect of using their networks, staff members are more likely to use hierarchical structures. In the context of a firm with a team structure and a single level of hierarchy, the above equation applies.

$$b = \sum_{i=1}^{n} \begin{cases} b_i - ct, & if\ \rho_i = yes\ and\ E(hier.) > \mathrm{E(team)}|\ b_i - ct > 0\ and\ b_i > 0\ with\ \pi \\ b_i - ct, & if\ \rho_i = yes\ and\ E(hier.) > \mathrm{E(team)}|\ |b_i| - ct > 0\ and\ b_i < 0\ \ with\ (1-\pi) \\ b_i - \dfrac{ct}{\pi}, & if\ E(hier.) < \mathrm{E(team)}\ |\ b_i > 0\ and\ \ b_i - \dfrac{ct}{\pi} > 0\ and\ \dfrac{c}{\pi} < Size\ Org. \\ b_i - \dfrac{ct}{1-\pi}, & \text{if}\ E(hier.) < \mathrm{E(team)}\ |\ b_i < 0\ and\ |b_i| - \dfrac{ct}{1-\pi} > 0\ and\ \dfrac{c}{1-\pi} < Size\ Org. \\ 0, & otherwise \end{cases}$$

Equation 6.4: Hybrid regression model

The results of the comparisons are shown below in Figure 6.3 below.



(a) Hierarchical model	(b) Cooperative model	(c) Hybrid model

Figure 6.3: A comparison of the potential profits generated by (a) hierarchical, (b) cooperative, and (c) hybrid (combining hierarchical and cooperative) models.

Figure 6.3 indicates that when staff have high decision-making ability, both cooperative and hybrid ways of working are advantageous (tending towards the top right-hand corner). On the other hand, if staff members erroneously perceive a poor innovation as good and promote it (incurring transaction costs), then these two models can result in the greatest harm (tending towards the bottom left-hand corner). In the latter case, retaining a hierarchy, even if the manager makes decisions based on a coin flip, inflicts the least harm, although gains are reduced.

In this simulation, the assumption has been that the university hierarchy is strict and monolithic, thus the ratio of “good” to “poor” innovations will be largely unchanged. Figure 6.3 shows that under these circumstances the best management structure for the TTO is competent teams of co-operators where decisions can occasionally be referred to a manager.

6.4 Conclusions and future work

At the smallest 10% of universities, managers may uncover ways of endorsing innovations; however, even when they are mistaken, the expenses incurred are not substantial. In such situations, the most suitable strategy may be ad hoc, without additional expenditures that maintain a Technology Transfer Office (TTO).

Large universities tend to operate within a highly regulated environment, which imposes a rather rigid management framework, as demonstrated by Albats et al. (2022). This study models the process of adopting innovations from researchers in labs and guiding them through a hierarchical decision-making structure for senior management in a large university. Once approved (whether deemed "good" or not), these innovations are then referred to the TTO for further processing and dissemination to external recipients (Harmon et al., 1997).

Large universities have many knowledge assets and possibly ambidextrous TTOs, while smaller universities have few knowledge assets and ambidextrous TTOs. Knowledge transfer occurs in the “Sweet Spot” between assets and ambidexterity as shown in figure 6.4.

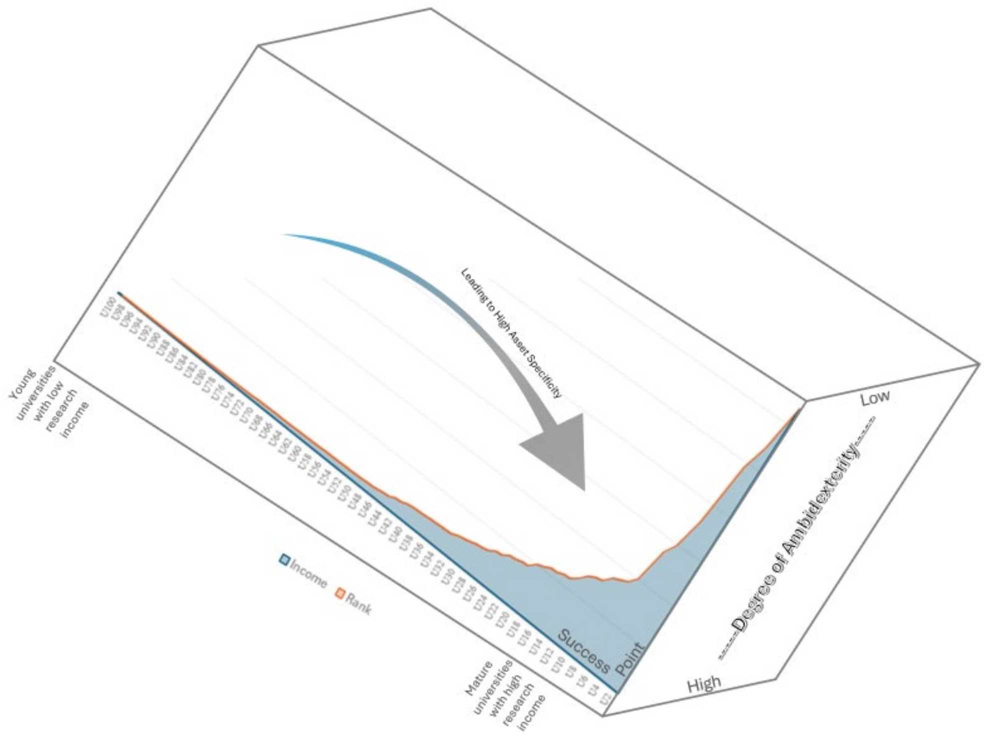


Figure 6.4: Factors in the success of university technology transfer offices (Author's own figure)

Interestingly, innovations transit across different types of environments from their conception; climb the university hierarchical management structure, across a hierarchical or co-operative/hybrid TTO into what is possibly a start-up (typically with flat or co-operative management structure), to Science Parks whose ambidextrous management structures are considered by e.g. Al-Kfairy and Mellor (2020). Distance working post-COVID may also be profoundly changing the nature of technology transfer to businesses, and "centres versus networks" is a rapidly evolving question (see e.g. Mondal et al. 2023), and clearly, more work needs to be done in this area to achieve better clarity.

The use of modelling approaches has its limitations, as Radko et al. (2022) highlighted the organisational architecture across various stages of entrepreneurship and the different profiles of universities involved. Similarly, Johnston (2020) and Audretsch and Belitski (2022) found that university-industry technology transfer depends on social, technological, and organisational alignment factors, which are not taken into account in this context.

Nevertheless, the modelling approach presented herein offers valuable insights into what to investigate. Future research could utilise panel data, as demonstrated by Vanino et al. (2019), to identify high-performance universities. These institutions can then be examined to determine their TTO management structure. According to this study's findings, large universities with competent and cooperative team structures are expected to be the most productive in managing TTOs.

Contribution of the Chapter

This study advances the understanding of entrepreneurial universities by emphasizing the pivotal role of Technology Transfer Offices (TTOs) in bridging innovation producers and users. By examining decision-making within diverse TTO management structures, it demonstrates that team-based or hybrid models improve performance, especially in larger universities with substantial knowledge assets. The study provides insight into hierarchical and cooperative management approaches, showing that effective decision-making within TTOs enhances the innovation pipeline and financial outcomes. Contributing to the Triple-Helix model, it underscores ambidextrous approaches that blend hierarchical and cooperative practices to optimize commercialization. Additionally, it highlights the challenges tied to university size and calls for further longitudinal research, especially regarding post-COVID impacts on technology transfer.

7 The economic rewards of knowledge spillovers from UK state-supported research: Investigating the innovation pathways to knowledge recipients

7.1 Introduction

Ever since Nobel laureate Paul Romer (Nobelprize.org, 2018) suggested that market economies alone generate insufficient numbers of new high-tech innovations to support national competitiveness, and therefore that '*well-designed government actions*' are required, an intensive debate has taken place around if state subsidies are effective in entrepreneurship and in regional development, and if so, under what circumstances.

For robust overviews the reader is referred to the works of Becker and co-workers (Becker, 2015; Vanino et al., 2019; Becker et al., 2023). However, in principle the narrow debate investigated here concerns Will and Mellor (2019), who used very large datasets from the Czech Republic, Germany, Hungary, Poland, Romania and the Slovak Republic and found that overall, state subsidies do not have any significant effect on the financial performance of recipient firms, whether that support is received through research councils or direct programmes. Conversely, in a large meta-review, Zúñiga-Vicente et al. (2014) investigated studies from USA and other developed countries including Austria, Belgium, China, Denmark, Finland, France, Germany, Ireland, Israel, Japan, the Netherlands, Norway, Spain and Sweden and found several instances of reports consistent with the above, as well as some contrary.

While many authors refer to 'knowledge spillovers' from innovation-producers to innovation users, who in turn intend to apply this knowledge to entrepreneurial and commercial ends, the innovation pathway taken is anastomose and parts are relatively poorly characterized. For example, Roper et al. (2022) emphasised that firms seeking innovation may differ in knowledge-acquiring approaches to those seeking imitation benefits. This highlights the role of the academic knowledge source and should ideally take into account the knowledge-acquiring status of the recipient (see Zieba, 2021) and the degree of novelty involved (Seidle, 2024).

In this work we strive firstly to shed light on the role of state funding to firms by looking at the performance of co-funded and non-funded firms in projects where the state gives support to the academic partner. Co-funded firms have a financial incentive, as well as pressure, to perform well, while non-funded firms are in an open innovation scenario where they can seek as many knowledge spillovers as they deem relevant.

Secondly, we seek to identify knowledge-producers that are successful in transferring innovations and will in future work use this as a springboard to investigate their innovation pathways.

To these ends we performed a longitudinal analysis of the financial performance of firms included in state projects, which enables the identification of over- and under-performing projects and their universities.

We used the UK 'Gateway to Research' (GtR) database to find those firms associated with funding from the UK research councils. The GtR data provides information on all state-supported research projects, including Innovate UK, the seven Research Councils and the National Centre for the Replacement, Refinement and Reduction of Animals in Research (NC3Rs). For this work we chose two culturally quite distinct sources, Innovate UK (budget of £1,200m/year) and the Arts and Humanities Research Council (AHRC) which has a budget of £102 m/year. All firms involved in state funded projects from these two sources between 2009 and 2012 were found and their Companies House registered number (CRN), postcode and SIC 4-digit level code were recorded. Using Companies House data (annual returns), these firms were then tracked for the decade 2012 to 2022 and for each year their annual economic performance was measured. For each firm the economic data from a random group of 6 firms of similar size in the same SIC category functioned as control.

In AHRC funded projects, higher education institutions or other research institutes (here both referred to as 'universities') take on the role of project coordinator, while firms and other corporate entities participate as non-funded partners that are interested in being exposed to nearby knowledge spillovers. Conversely, Innovate UK projects aim at the commercialisation of innovations and operates differently, with a funded university lead and much support going to firms within the UK.

7.2 Methods and Data Sources

To conduct our analysis, MS SQL Server was used for storing the data in the large (~2.5 GB) dataset and extracted using Python. ArcGIS Pro was used for mapping and MS Excel with Minitab for financial analyses.

GtR provides information about ~34,000 organisations that have participated in state-supported projects. However please note that the GtR data relates exclusively to the state contribution and does not provide data about other financial contributions by firms or other organisations. The datasets are publicly available on https://gtr.ukri.org/

Those projects granted between 2009 and 2012 from AHRC and Innovate UK that contained an industrial partner were selected and the industrial partner identified from its Company Registration Number (CRN) as displayed on the public register of companies and the corresponding SIC code(s) retrieved. Companies House registers company information and also makes it available to the public, including providing economic data in the form of annual company returns (in iXBRL format), which were extracted and used to gauge company performance. The datasets are publicly available on

https://www.gov.uk/guidance/companies-house-data-products

The number of projects investigated was 266 (AHRC 63 and Innovate UK 203). AHRC and Innovate UK combined showed the total number of universities involved was 90 together with 368 firms in 169 SIC codes. In those 91 instances where only 1 SIC code was involved, trimmed estimators were used, resulting in a nonparametric skew. Those cases which lack the volume for individual statistical accuracy, were pooled and are presented separately.

The SIC codes involved in the projects are presented in Appendix Table 10.1.

Appendix Table 10.2 shows the number of projects investigated (designated randomly), the number of academic and industrial partners and links these to the leveraging Standard Industrial Classification (SIC) Codes of the industrial partners and their distance in km from the academic lead partner.

7.3 Results

In this study, we conducted a comprehensive analysis of funded firms, leveraging Standard Industrial Classification (SIC) Codes to segment and categorise their longitudinal performance as compared to the performance of 6 randomly chosen firms of comparable size in the same SIC code.

The results are broken down into several parts, firstly those looking at clustering of firms, secondly by analysing financial performance according to the funding source and thirdly by analysing comparative performance by industrial sector.

7.3.1 Who funds what?

The different foci of the two research councils can be seen in the SIC codes of the associated firms, the top 3 SIC codes for firms involved in Innovate UK projects were 72190, 32990, 26110 and for AHRC the 3 top SIC codes were 90030, 85590, 87300, thus the two research councils appear to fund largely diverse industrial areas and there appears to be little overlap in the major areas of interest.

However, the two funding sources, Innovate UK and AHRC, did show some overlap in the more minor areas of interest expressed by the incorporated partners in projects. Table 7.1 shows where interests overlap, that SIC 72190 (Other research and experimental development on natural sciences and engineering) were of larger interest to Innovate UK, and 90030 (Operation of historical sites and buildings and similar visitor attractions) was of more interest to AHRC.

Table 7.1: The SIC codes of common interest to both Innovate UK and AHRC.

SIC Code	Innovate UK		AHRC	
	No of Projects	No of Firms	No of Projects	No of Firms
26200	2	2	1	1
70100	9	6	1	1
72190	60	21	4	3
74909	21	7	5	5
82110	1	1	1	1
85590	1	1	8	5
88990	1	1	4	4
90030	1	1	10	5
96090	36	5	1	1

7.3.2 Geographical Clustering

Of the AHRC-associated firms, 14 projects (22.2%) out of 63 had firms within 30 km. For example AHRC36 had 2 firms close by, but conversely project AHRC22 had 3 firms, all over 200 km away. The closest example to a local cluster was project AHRC59, a cluster of 8 close firms, but that project also contains one far (>100 km) away.

Of the Innovate UK-associated firms, 21 projects (10.4%) out of 203 had firms within 30 km. The closest examples to a cluster were InnoUK21, InnoUK56 and InnoUK202, all of which had 2 firms close by the project lead. Conversely project InnoUK154 has 6 firms, all over 100 km away. Table 7.2 shows the overall results regarding proximity.

Table 7.2: The mean and median distances between firms and principal universities (project leads) for AHRC and Innovate UK projects.

AHRC Projects Mean:	123.36 km	InnoUK Projects Mean:	157.56
AHRC Projects Median:	101.17 km	InnoUK Projects Median:	135.23

7.3.3 Financial Analyses: Comparing the two Research Councils

Figures 7.1 and 7.2 show the aggregated performance of firms associated with AHRC projects (figure 7.1) and Innovate UK (figure 7.2) in the decade following their involvement in the projects. As can be seen from these figures, both Innovate UK- and AHRC-associated firms showed on average a superior performance. Those firms associated with AHRC projects showed about 20% superiority to the control group while those firms associated with Innovate UK projects showed about 18% superiority to the control group. Interestingly in both cases a pronounced dip occurs during the Covid pandemic, somewhat more pronounced for firms associated with AHRC projects than those associated with Innovate UK projects.

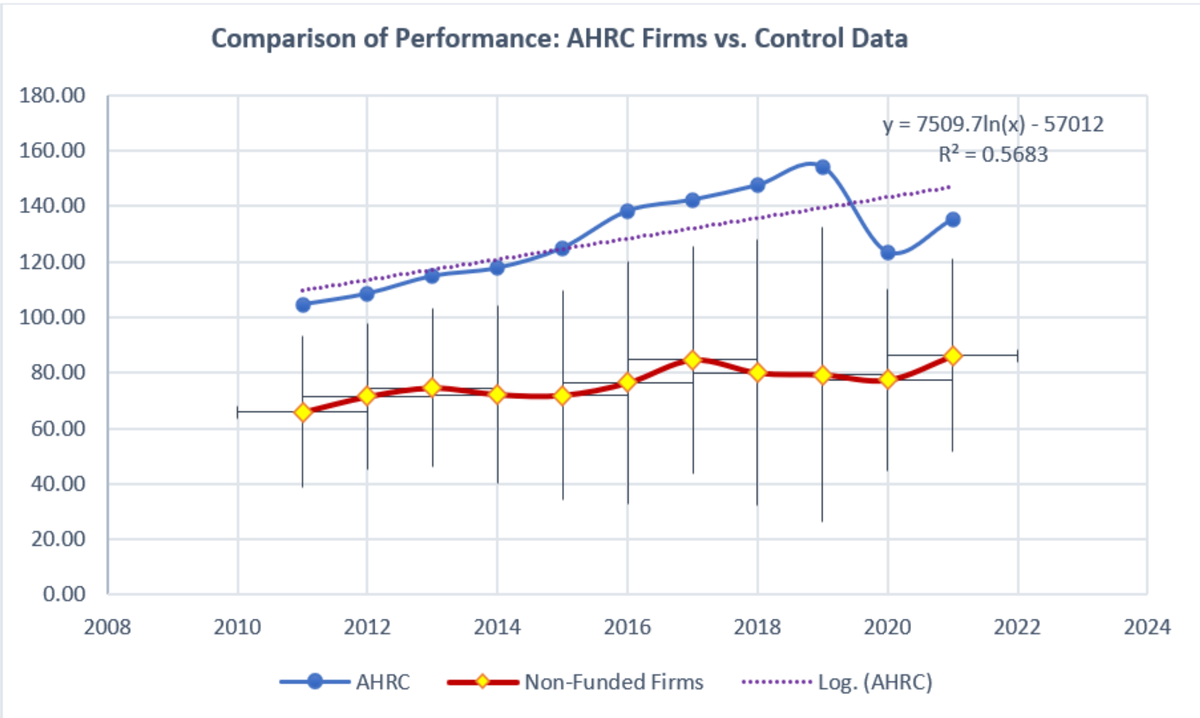


Figure 7.1: Aggregated performance data of all AHRC firms compared to the aggregated control data (non-funded firms). On the x-axis is year and on the y-axis is annual turnover in £mio.

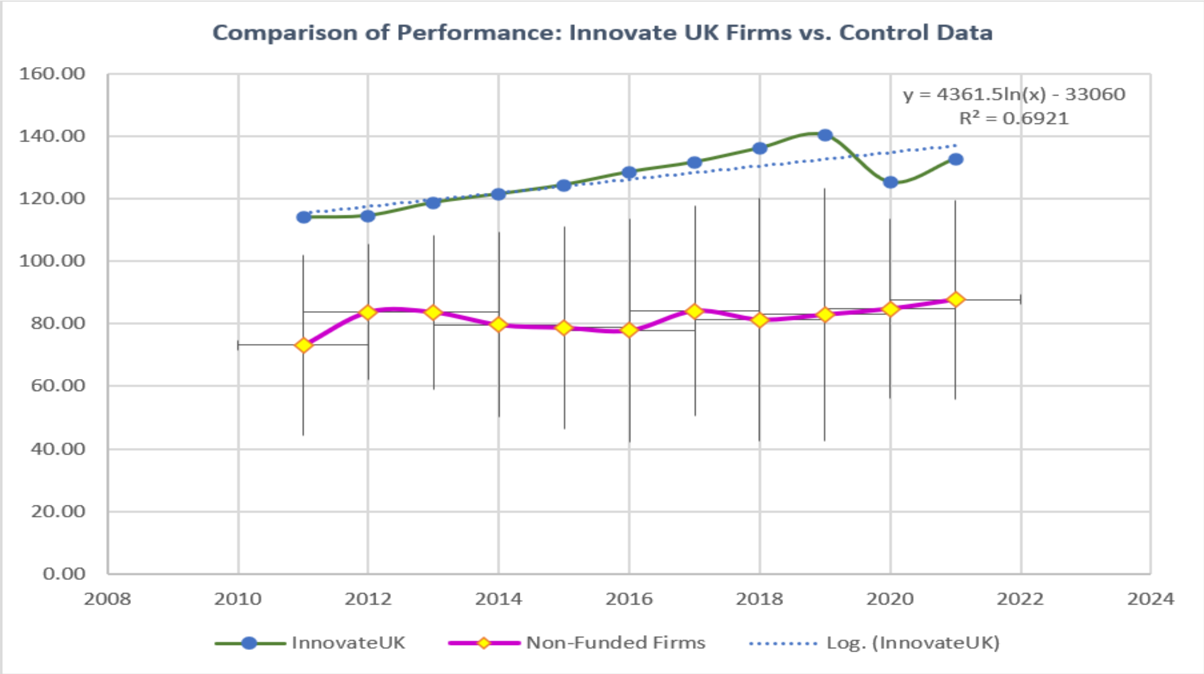


Figure 7.2: Aggregated performance metrics of all Innovate UK-funded firms are contrasted with the aggregated control data from non-funded firms. On the x-axis is year and on the y-axis is annual turnover in £mio.

91 instances were recorded of entries in only 1 SIC code, which defies meaningful analysis. Thus these examples were pooled and the aggregate performance compared to the aggregated control firms for these SIC codes.

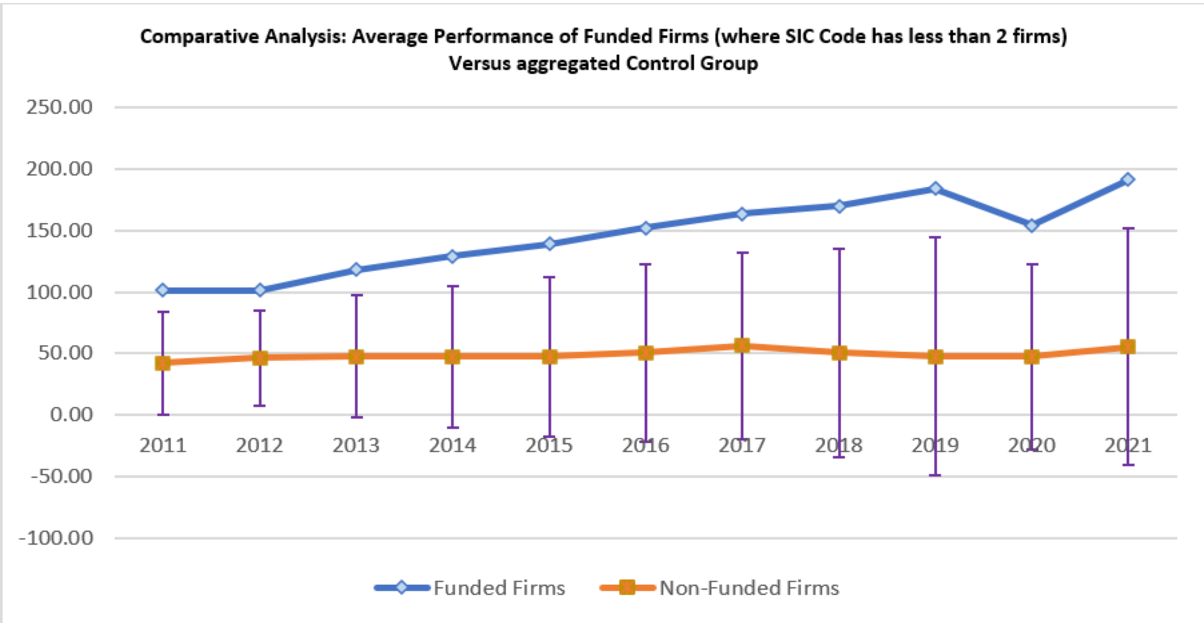


Figure 7.3: The average financial performance of the 91 outliers versus aggregated control group. On the x-axis is year and on the y-axis is annual turnover in £mio.

Skewed outliers: Figure 7.3 shows the pooled performance against pooled controls. Should the outliers have exhibited a poorer performance that controls then further investigation would have been required. However, this was not the case, thus generally the results in figure 7.3 tend to lend believability to the results shown in figures 7.1-7.2 and table 7.3.

Nonetheless, given the uncertainty due to few firms (hence the pooling), the aggregate results, while optimistic overall, may not mirror the true picture for all outlier firms.

7.3.4 Financial performance by SIC code

In table 7.3, we conducted an analysis of firms data according to the source of funding.

Table 7.3: Performance of firms in selected SIC codes that were associated with either AHRC or Innovate UK funded projects in the 10 years post-project.

SIC Code	Average Gradient for AHRC	Average Gradient for Innovate UK	Average Gradient for Control Group
26200	-70.50636364	6.10672727	-32.19981818
70100	229.30818182	6.99190909	118.15004545
72190	0.16818182	-0.18063636	-0.00622727
74909	0.19227273	1.29927273	0.74577273
82110	-0.01709091	-1.89981818	-0.95845455
85590	0.17027273	-0.01154545	0.07936364
88990	0.03209091	0.73254545	0.38231818
90030	0.23518182	-2.72009091	-1.24245455
96090	0.04863636	9.26854545	4.65859091
85520	0.36063636		0.03727273
86900	0.80681818		0.02463636
90010	0.01300000		0.03090909
90020	-0.02863636		0.26809091
90040	0.21027273		0.05809091
91011	2.36709091		0.16990909
91020	3.59318182		0.05581818
94120	0.39945455		0.00581818
94990	-0.00418182		0.02300000
01110		0.61336364	-0.00463636
01470		3.06072727	-0.09809091
01610		2.06845455	0.01454545
01629		0.85127273	0.00081818
03210		4.47454545	-0.06945455
09100		-7.55181818	0.18536364
10390		3.82618182	0.28727273
10611		0.66190909	0.00836364
10710		2.18363636	-0.00136364
10850		25.99309091	3.88645455
10890		6.33518182	2.33627273
10910		-2.49409091	3.92809091

13200		1.72663636	0.15681818
20110		7.48281818	-0.02081818
20130		2.04236364	-0.01418182
20140		9.89772727	-1.84418182
20150		-15.63663636	0.01945455
20160		-4.73509091	-0.13054545
20590		2.75163636	-0.30663636
21100		7.88909091	0.02809091
22210		-0.29200000	0.39890909
22290		-2.25854545	0.05854545
25110		1.62163636	0.00045455
25500		-2.26272727	-1.27854545
25610		0.28936364	-0.27263636
25620		-34.63790909	0.09154545
25990		2.98836364	0.04581818
26110		10.31936364	0.15818182
26309		0.60663636	0.34490909
26511		1.96736364	0.01563636
26512		22.87481818	0.14145455
26701		2.12463636	0.07227273
26702		-0.46818182	-0.31572727
27110		1.80800000	-6.02836364
27120		-6.84718182	5.26763636
27900		-0.23981818	-0.00754545
28302		0.72609091	0.36654545
28930		4.10536364	3.48254545
28990		-13.97090909	0.09590909
29100		15.01809091	2.26836364
29320		-1.68645455	-0.08109091
30120		4.96027273	-0.00490909
30300		4.52718182	-0.08645455
32500		8.91645455	0.00645455
32990		26.75490909	0.00309091
36000		9.42009091	0.01709091
41100		23.08509091	0.13181818
42220		17.56490909	1.71727273
43999		0.46181818	0.04254545
46110		3.97609091	0.30518182
46310		-0.55318182	0.04463636
46720		1.61127273	0.27109091
49410		11.20381818	0.07954545
52103		3.89681818	-3.56181818
61200		-2.78790909	-0.08172727
61900		4.59154545	1.96600000
62012		0.99054545	-1.86754545
62020		3.21809091	2.37045455
62090		0.49081818	-0.10618182
70229		1.64045455	0.03554545
71121		-1.91309091	-2.23054545
71122		17.92654545	0.69327273
71129		2.80927273	0.03290909

72110		3.00545455	0.08572727
73110		-2.71027273	-0.48045455
74901		-3.75254545	-0.21227273
82990		0.92945455	0.15272727
84220		14.63845455	-2.00645455

Table 7.3 shows that firms in several SIC codes did not fare as well as the control group over time. These SIC codes are 85520 (Cultural education), 88990 (Other social work activities without accommodation), 90010 (Performing arts), 90040 (Operation of arts facilities), 90020 (Support activities to performing arts) and 94990 (Activities of other membership organisations). This was especially stark in 90010, 90020 and 94990, where firms included in projects were not only outperformed by the control group, but their performance also stayed flat over a decade, with no improvement.

Conversely, firms in SIC codes 72190 (Other research and experimental development on natural sciences and engineering), 74909 (Other professional, scientific and technical activities n.e.c.) and 91020 (Museum activities) all started ahead of the control group and maintained their lead throughout.

Between there groups were firms that managed to differentiate themselves from the control group. SIC codes for these firms were 85590 (Other education n.e.c.), 91020 (Museums activities) and the popular – see table 7.3 – 90030 (Artistic creation).

SIC codes associated with both AHRC and Innovate UK funding were 26200, 70100 and 96090. AHRC-associated firms in 26200 (Manufacture of computers and peripheral equipment) performed below control while Innovate UK-associated firms performed above control. In 96090 (Other service activities n.e.c.) AHRC-associated firms performed below control while Innovate UK-associated firms performed above control. Conversely in 70100 (Activities of head offices) AHRC-associated firms performed excellently, well exceeding control, while Innovate UK-associated firms performed well below control, similarly in 90030 (Artistic creation) AHRC-associated firms outperformed both control and Innovate UK-associated firms while the following associated with Innovate UK were outperformed by control; 09100, 20150, 25620, 28990, 73110, 74901, 94990 and 90020. An overview of the best-performing SIC codes is given in table 7.4.

Table 7.4: The 10 financially most successful SIC codes (for descriptions see Appendix Table 10.1) from most successful, descending, as associated with either AHRC or Innovate UK. Asterisk denotes popularity of that SIC code amongst the research councils, as given in Table 7.1.

SIC Code, AHRC	SIC Code, Innovate UK
70100 *	26200 *
91020	32990
91011	41100
90030 *	26512
82110 *	10850
86900	71122
94120	84220
85520	42220
72190 *	29100
90040	20140

Paradoxically, a comparison of table 7.1 and table 7.4 shows that the majority (15/20) of the successful SIC codes are not 'core' to the research councils involved.

7.3.5 Success in knowledge transfer

The SIC codes in table 7.4 allow the project number to be identified (as in Appendix Table 10.2) and hence the university leading the project. These 266 project leads (90 universities) can be ranked accordingly to the financial performance of the associated firms, leading to a measure of their success. Figure 7.4 shows that universities have a broad range of success, as measured by the financial performance of associated firms measured over 10 years post-project. Nonetheless, 83 (31%) there was negligible (<1% increase in revenues over control) gain for firms associated with these funded projects. Figure 7.4 shows the distribution range of success, as measured by percent growth in turnover of the firms associated with the state-funded projects. Figure 7.4A shows in particular that many firms received large boosts to their turnover after being part of AHRC projects, while Figure 7.4B shows that a significant proportion of firms in Innovate UK projects performed relatively disappointingly after the project was concluded.

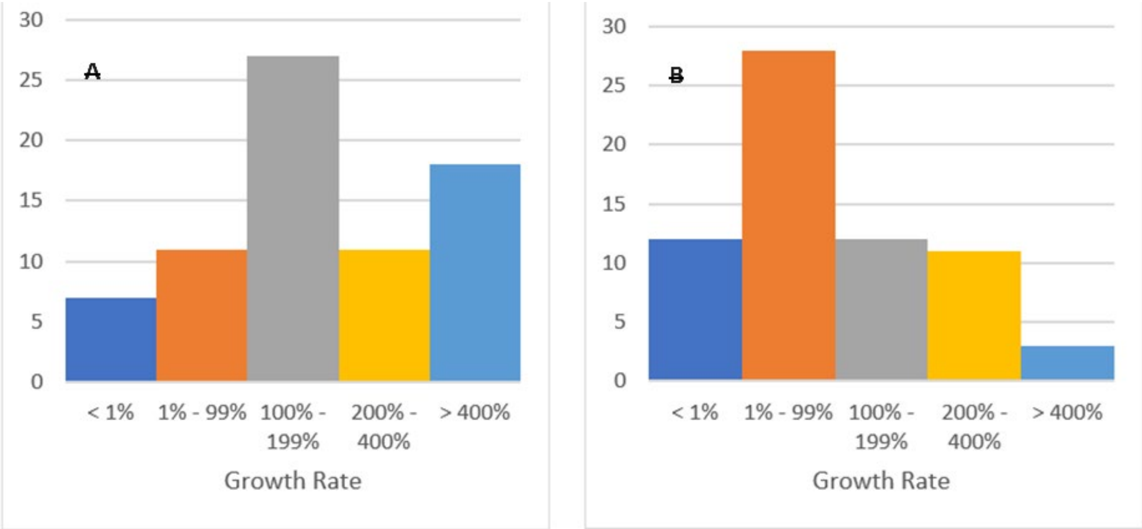


Figure 7.4: The growth rate of firms associated with (A) AHRC and (B) Innovate UK across universities. On the x-axis is increase in annual turnover vs control of firms associated with the two research councils' grants, and on the y-axis is number of universities.

Closer analysis showed two non-overlapping sets, one set of 21 universities (18.9%) whose associated firms performed >200% of control, and a second set of 24 universities (21.6%) whose associated firms performed <1% of control. Note that the number of universities in figure 7.4 exceeds a total of 90 due to some universities falling into more than one group.

7.4 Discussion

7.4.1 Geographical Analysis

Regarding geographical proximity, for German firms, Holl et al. (2022) found that the strength of knowledge spillovers that contribute to innovation in firms falls off with distance, vanishing to zero beyond 30 km. Similarly, Rodríguez-Pose and Comptour (2012, p.280) said '*Physical proximity is often regarded as the key aspect making some regions genuine loci of innovation. The basic reasoning is that innovation travels with difficulty and suffers from strong distance decay effects*'. Using the concepts of distance decay (Pun-Cheng, 2016), Helmers (2019, p.31) also found '*knowledge spillovers decay rapidly with geographic distance*'.

In this study the figures for projects funded by Arts & Humanities Research Council show only 21 firms within 30 km for the principal university, out of 63 projects funded. Similarly, the figures for projects funded by Innovate UK show only 42 firms within 30 km for the principal university, out of 203 projects. This finding implies agreement with Johnston (2022) insomuch as asset complementarity (expressed as inclusion in a project) appears to be more important than distance.

Distances between the project lead university and firms are given in Appendix Table 10.1 and the mean and median distances for both funding sources are given in table 7.2.

These results correlate well with the findings of Mondal et al. (2021) who found no evidence of agglomeration of specialised firms around universities. Mondal et al. (2021) also looked at non-university innovation sources, namely Science and Technology Parks (STPs) and found that in the UK, there exists a limit of 32km from an innovation source (in this case an STP) to the next STP with the same specialisation. Kussainov et al. (2020) also found that specialised firms are to be found in an annular ring of 4-8 km around specialised STPs (for recent overviews of STPs in this respect, see Mondal et al. 2023), but in agreement with the tendency reported here, neither Mondal et al. (2021) nor Kussainov et al. (2020) could find evidence of co-location of specialised firms around universities in the UK. Thus, Holl et al. (2022) are not incorrect about the distance effective knowledge spillovers contributing to innovation in firms in those cases where an STP is the knowledge source although it is unknown if in the case of spillovers from STPs, if this involves innovation or imitation (see Cappelli et al. 2014). However, in the case of universities as knowledge sources, results show that distance is only a minor factor (c.f. Roper et al. 2017) when compared to the pull of asset complementarity Johnston (2022). This is an important distinction because STPs are dependent on attracting firms (see e.g. Mondal and Mellor, 2021) for growth, but universities are not dependent on industrial partners to flourish.

7.4.2 Financial Analyses: Innovate UK compared to AHRC

In figure 7.1, the performance of AHRC firms demonstrates a consistent upward trend from 2012 to 2022, with occasional fluctuations. This trend indicates steady growth and suggests that funding has positively influenced the performance of these firms over the years. However, there is a notable deviation from this trend in 2020, where performance sees a significant decline. This deviation may be attributable to the unprecedented challenges posed by the COVID-19 pandemic.

The provided regression equation indicates a logarithmic relationship between the time and performance. It suggests that as time progresses, the performance of firms increases logarithmically; the overall growth rate for AHRC was 29.39%.

In figure 7.2, the comparative analysis reveals distinct performance trends between funded (Innovate UK) and non-funded firms over the analysed period. Innovate UK firms consistently outperform non-funded firms across the years, indicating the potential positive impact of funding on firm performance.

The regression equation indicates that performance growth follows a logarithmic pattern over time. The relatively high R^2 value of 0.6921 suggests that the model explains a significant portion of the variability in the data, implying a relatively robust fit of the regression model.

On average, firms associated with state granting schemes initially appear to have received a lasting boost to performance, however other interpretations are possible, for example one could postulate that these, more innovative firms, would have had superior performance anyway, only that, as innovative entities, did they seek membership of a state-funded project. They may also have been directly funded by further projects, after 2012.

Thus, while a correlation can clearly be seen, causality has not been firmly established.

7.5 Conclusion

The results presented imply that firms that are part of state-funded consortia receive a 'knowledge boost' from the academic partner(s), leading to their aggregated superior financial performance.

Of the independent variables:

(1) The idea that the research councils differing interest areas have a large effect appears largely substantiated, but absolute confirmation requires an analysis of the remaining 5 councils.

(2) The idea that industry sector (SIC code) affects firm performance is largely substantiated. However and paradoxically, the best-performers were not predominant in those sectors that appear popular with the research councils.

(3) Co-funding of firms appears on average not to be a significant factor in boosting firms finances in that non-funded firms appear on average to perform better and that many co-funded firms performed under control.

(4) The data indicates that some universities spread throughout the UK regions consistently give a significant 'knowledge boost' to associated firms, while others, equally spread, consistently do not. The reason for this remains unknown.

However, when we drill down to industrial sectors, a much more nuanced picture begins to emerge, possibly illustrating that Big Data approaches (e.g. Will and Mellor, 2019) may miss the fine detail. For example, there is no indication of how much product innovation has been achieved *versus* process innovations (see Cappelli et al., 2014). Especially concerning, is that causality has not been proven and other mechanisms may affect results; perhaps the over-performing firms invited into state projects by universities are simply gazelles that would have performed better anyway? The results presented here show average improved financial performance, but do not definitely pin-point the cause.

7.5.1 The role of state support for private industry

Transferring knowledge requires at least 2 partners; a donor and a recipient. The results presented here show that on average, firms associated with some knowledge donors perform on aggregate financially better than control firms. However, the more detailed results from SIC codes reveal that in most SIC codes performance is comparable or under control values but the average is boosted due to there being a few over-performers, who perform very well (Table 7.3). Conversely, under-performers may face challenges in accessing resources or scaling their operations while facing other costs, as discussed by Vivona et al (2022).

One possible factor is the ability of firms to accept and incorporate innovations (Zieba, 2021) in an efficient manner (for an overview of this topic, see Bhadauria and Singh, 2023) but unfortunately there exists a paucity of comparative studies examining technology acceptance in different industries at the SIC level of detail (for a recent general review of the Technology Acceptance Model, see Musa et al, 2024).

7.5.2 Who performed well in knowledge transfer?

The study identified 21 universities where associated firms consistently over-performed up to and over 400% above control, and 24 universities whose associated firms consistently under-performed (<1% above control). The other 45 universities gave a mixed picture. These results are reminiscent of those presented by Huang et al (2024) investigating a related topic, graduate entrepreneurship, and who concluded "*neither university entrepreneurship support, knowledge exchange intensity, regional economic prosperity, nor entrepreneurial culture, on their own, are sufficient to explain the outcomes*" and a similar situation is reported here for university technology transfer offices and their interaction with entrepreneurial knowledge-seeking firms.

7.5.3 Future research

It is tempting to speculate that the universities at the extremes will be the subject of comparative follow-up case studies investigating the management architecture of their respective knowledge transfer mechanisms (Mondal et al., 2024) and how this relates to management transaction costs (Mellor, 2016).

Contribution of the Chapter

This study makes a significant contribution to the literature on knowledge spillovers from state-supported research by examining the economic rewards for recipient firms and the factors shaping effective knowledge transfer pathways. Utilizing the UK's Gateway to Research (GtR) and Companies House data, it conducts a longitudinal analysis of firm performance following funding, with a focus on firms involved in AHRC and Innovate UK-supported projects. The research provides a nuanced view of how sector (via SIC codes), geographic proximity, and research council priorities influence firm outcomes. It reveals that state funding yields varied financial impacts across sectors, significantly shaped by institutional factors, such as the academic lead's expertise in knowledge dissemination. By highlighting sector-specific and institutional differences in knowledge transfer effectiveness, the study suggests that examining the management structures of top-performing universities could uncover best practices to maximize the economic benefits of public research investment. This work underscores both the potential of targeted state funding to enhance firm performance and the complexity of knowledge spillovers, offering a strong foundation for future research on optimizing public-private research partnerships for regional and national economic growth.

8 Thesis Conclusion

This thesis explores various aspects of Science and Technology Parks (STPs), such as the role of large companies within STPs and the impact of university collaboration on innovation and performance within high-tech entrepreneurship. It examines the influence of large companies on the decision-making processes of STPs, analyses the spatial relationships between universities and STPs, reviews traditional models of university-industry collaboration, and evaluates the performance outcomes of firms that receive university grants. The overarching goal of this comprehensive study is to provide a deeper understanding of the structural and managerial factors that contribute to the success of high-tech ecosystems.

8.1 Summary of Findings

Nobel laureate Paul Romer highlighted the importance of "*well-designed government actions*" to foster technological innovation in market economies, which often fail to generate new ideas (Nobelprize.org, 2018). This encompasses initiatives such as research and development subsidies, university funding, and the establishment of science and technology parks. Despite the significance of stakeholder engagement in national industrial strategies, there remains a notable research gap due to the scarcity of clear data-driven indicators that demonstrate the contributions of research councils, governments, STP organisations, and local businesses.

The notion of an entrepreneurial university highlights the paradox that academics have strong credentials but low entrepreneurial intent and experience, which challenges the effectiveness of university spinouts (Hegde and Tumlinson, 2020). The findings of this study indicate that early and mid-stage STPs often fail to capture sustainable commercial applications, and on-campus STPs do not necessarily attract serious industry interest (Mondal et al., 2021). Micro-firms typically exit the STP within five years or expand into larger enterprises while remaining there (see Figure 5.3). To avoid stagnation and maintain a high level of innovation, STPs need a steady influx of new ideas and the presence of at least two large firms over a 20-year period. Without these factors, the STP's growth becomes stagnant or reverts to a low-innovation status. Intellectual interactions between universities and firms often require specific assets, aligning with Johnston's (2019, 2020) findings, which may be more prevalent in larger universities. Moreover, the sustainability of STPs depends on factors such as location, population density, and organisational behaviour. The effective management of STPs involves transitioning from simple to complex organisational structures to handle collaboration and conflict (Will and

Mellor, 2022). The spatial arrangement of STPs also affects their success, with non-competing STPs being closer together and competing STPs needing to be further apart.

This study examines different approaches to innovation management and technology transfer between small and large universities. In small universities, ad hoc methods without a formal Technology Transfer Office (TTO) may suffice due to lower stakes, as it avoids the administrative burden associated with having a formal Technology Transfer Office (Albats et al., 2022). In contrast to the structured and regulated environment of large universities, innovation uptake requires formalised pathways. This approach can impact the efficiency and effectiveness of technology transfer, as noted by Harmon et al. (1997). Innovations progress from lab research through hierarchical university management to TTO for further processing and potential commercialisation. Science Parks, with their ambidextrous management structures, contribute significantly to this transition, as indicated by Al-Kfairy and Mellor (2020). This study emphasises the dynamic nature of technology transfer, which is influenced by factors such as post-Covid remote work. It is anticipated that well-functioning cooperative team structures will be most effective for technology transfer offices in large universities.

The study also examines the impact of state-funded consortia on firms' financial performance, highlighting the significant role of academic partnerships in providing a "knowledge boost." While firms in these consortia generally perform financially better, the effect varies widely across different industry sectors and universities. The influence of the research councils' specific interests and the efficiency of knowledge transfer mechanisms are key factors, although the exact reasons for the observed performance disparities remain unclear. This study suggests that while state support can enhance firm performance, the complexity of these interactions necessitates further detailed research to fully understand the underlying dynamics.

8.2 Research Progress and Its Contribution

The findings of this study offer significant contributions to both academic debate and practical application. Through an investigation of the function of Science and Technology Parks (STPs) in regional economic growth and innovation, this research elucidates essential determinants for their success. This section will delve into the alignment and divergence of these results with existing theoretical concepts.

8.2.1 Enhanced understanding of STP dynamics

When this research began, the model for start-up STP development proposed by Ketels (2017) was the basis.

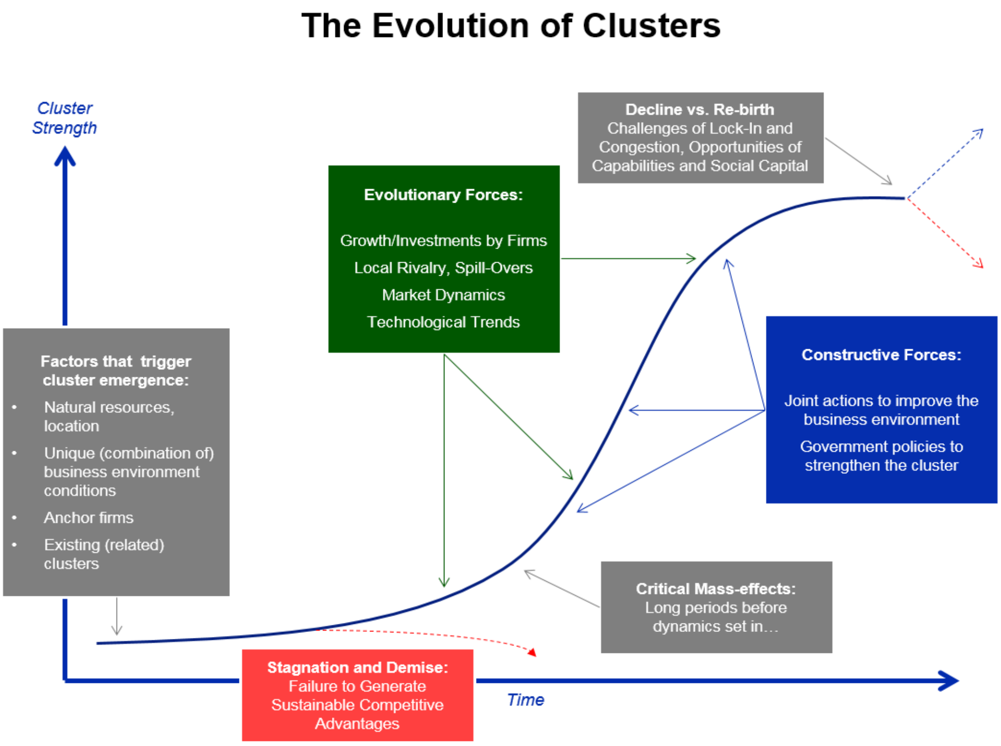


Figure 8.1: The Evolution of Clusters (Ketels, 2017)

However, Ketels' model (figure 8.1), despite being a student and protégée of Michael Porter, had some limitations. The forces named in the model were too vague, and the absence of units for time, etc., made it quite unsatisfactory. The model developed in this lab by Mondal et al. (2023) is a significant improvement in comparison (see figure 5.3).

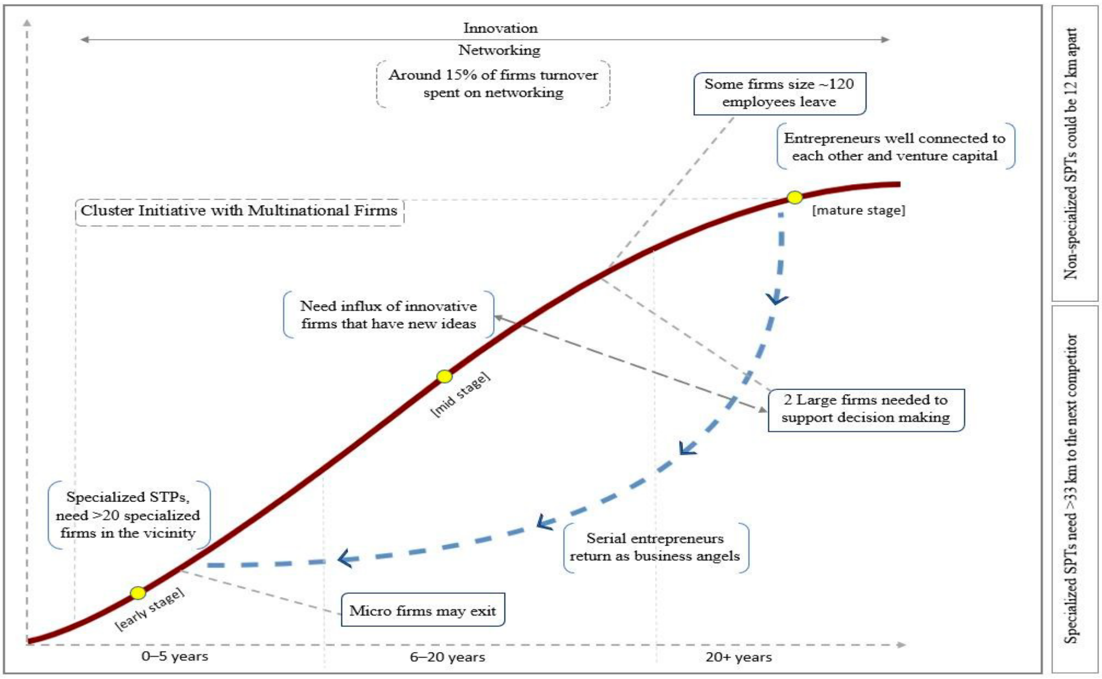


Figure 5.3: STP Life Cycle Model – A Graphical Overview of the Findings. (Author's own model)

The figure shows that micro-firms in Science and Technology Parks (STPs) typically exit or expand within a five-year period. The continued success of STPs depends on a steady influx of innovative ideas and the attraction of two large firms, which are vital for informed decision-making. Without these elements, STPs risk stagnation. Firms usually leave STPs once they reach around 120 employees and often relocate to nearby areas.

The outcomes of this research make a substantial contribution to the theoretical comprehension of the development and growth of Science and Technology Parks (STPs) and their impact on regional development. The contrasting growth patterns between on-cluster and off-cluster businesses underscore the need for refined theoretical frameworks and consider the symbiotic relationships that exist within STPs and their surrounding areas. This research endorses and expands upon existing theories, such as the innovation-based theory of the firm (Mellor, 2015; Costello, 2019) by emphasising the role that larger partners play in enhancing decision-making and promoting the continued growth of STPs.

8.2.2 Revisit of 'Triple-Helix' model

The classical Triple Helix model, as originally proposed by Etzkowitz and Leydesdorff (1995) is still in 2023 being propounded relatively unchanged, as here with unfortunate typos by Figueiredo et al. (2023).

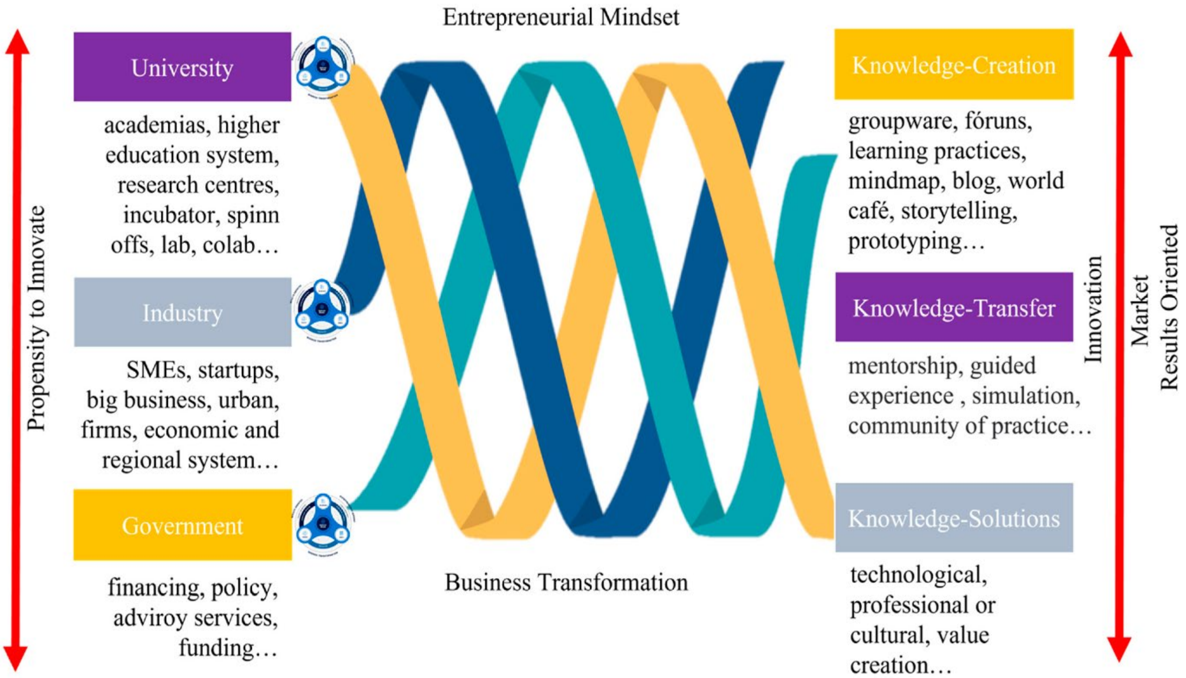


Figure 8.2: Framework to Integrate the Spinner Innovation and Triple Helix Models. Figueiredo et al. (2023).

However, data presented in this work shows that firms do cluster around STPs and not universities. Data presented in this thesis shows actual units being applied to the dimensions, for example, the spacing in km between STPs, and this represents a superior model and, thus, may necessitate modification of the Triple Helix to account for the dynamic nature of STPs their initiation processes and background density of specialised SMEs and other firms. Classically, the sequence and prioritisation of the model's three core functions of the knowledge-based economy, which are economic wealth generation, scientific and technological innovation, and systemic oversight, remain inadequately addressed. The conventional triple-helix framework lacks clarity on how these functions interact and in what order they should be emphasised, which could impact the effectiveness of strategies designed to harness the model’s full potential.

Moreover, the rapid advancement of decentralising technologies via e.g. the Covid pandemic has introduced new dimensions and technologies that have transformed technology entrepreneurship and business management, leading to the loosening of previously tight interconnections between academia, industry, and government. Consequently, the model must be updated to reflect these changes and integrate new sustainable practices that align with the contemporary decentralised environments. This evolution is essential for maintaining the relevance and efficacy of any model in today's dynamic landscape. Additionally, emerging research on intellectual interactions between universities and firms has revealed challenges related to asset specificity, not a previous Triple Helix factor. Johnston and co-workers (Johnston and Huggins, 2018; Johnston, 2019; Johnston, 2020) have noted that these interactions often exhibit narrow asset specificity, suggesting that the Triple Helix model may function more effectively in the context of large universities with extensive academic resources. This insight raises important questions about the model's adaptability across different institutional sizes and configurations, highlighting the need for a more nuanced approach to understand and apply an updated framework.

8.2.3 The Entrepreneurial University and Tech Transfer

As recently as 2022 (Sutopo et al., 2022) published a model they called "Death Valley" which plots a theoretical course from conception through tech transfer to success (or not) through a "Decision-Making Unit", which here is called "Technology Transfer Unit" although other labels can be found in the literature.

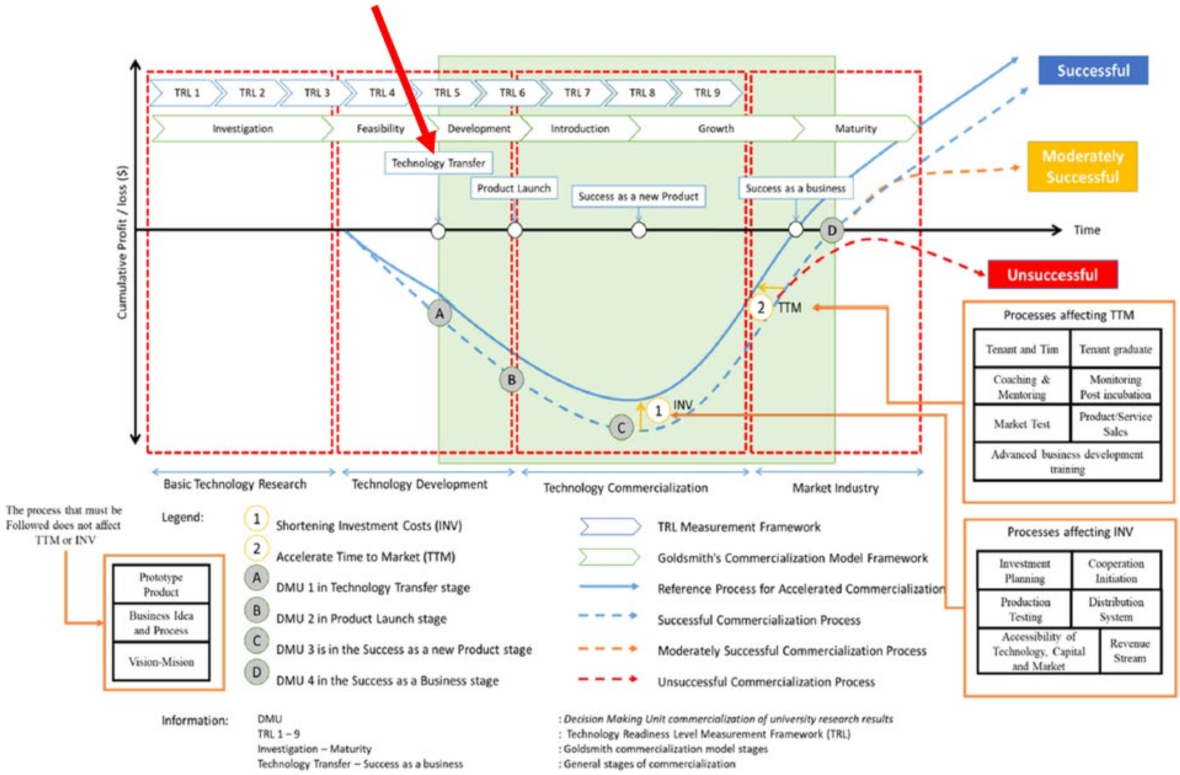


Figure 8.3: Picture of the death valley skeleton of the incubation process. (Sutopo et al., 2022)

Using the ideas of Stiglitz, modelling showed that the governance of such a unit could be different from that of the university hierarchy. Following on from this, "knowledge spillovers" were sought from UKRI grant partners, and ~20 universities identified whose commercial partners consistently over-performed against control, and ~20 universities consistently under-performed against control. Clearly the next work could be to investigate and compare the management structure of the TTOs at these universities.

Concerning state subsidies, overall in the UK it can be seen that:

a) State funding to universities with unfunded firms can have very positive effects on firms, where some universities consistently have a large effect, and other universities not (Chapter 7)
b) The effect of state funding on firms involved with co-funded universities is unclear; the figures presented here show an 18% benefit over control (comparing 20% with unfunded firms), while the SQW group (2023) reports that funded firms experience a 16% boost (SQW Report, 2023).
c) State funding directly to firms has overall no effect on research contributions as a whole (Will and Mellor, 2019)
d) State direct funding to STPs is largely determined by political expediency and results in a high failure rate.

Each research aim, objective, and deliverable outlined in the thesis is revisited, with a clear account of how each has been accomplished throughout the research. Below is a focused summary of where these achievements are integrated within the thesis:

1.2.1 Evaluate the Development and Sustainability of On-Cluster vs. Off-Cluster Firms in STPs

This objective is achieved in Chapter 3 and Chapter 5. Chapter 3 presents a comparative analysis of on-cluster and off-cluster SMEs within Science and Technology Parks (STPs), revealing the importance of larger partner firms in enhancing decision-making and supporting sustainable growth. Chapter 5 builds on this by identifying key factors, such as firm specialization and innovation alignment, essential for long-term STP sustainability. Together, these chapters provide insights into the contrasting growth patterns and performance of on-cluster and off-cluster firms, thereby addressing the first objective.

1.2.2 Optimize Collaboration and Foster Innovation within STPs

This aim is explored in Chapter 4 and Chapter 6. Chapter 4 examines spatial and sector-specific factors in STPs, particularly within the pharmaceutical industry, offering a model for achieving optimal proximity and critical mass among specialized firms to maximize collaboration. Chapter 6 expands on this by evaluating collaborative frameworks, such as the Triple Helix model, to highlight how partnerships with universities and industry stakeholders facilitate innovation. These chapters collectively address the objective of optimizing collaboration and innovation within STPs.

1.2.3 Establish a Sustainable Tech Entrepreneurship Ecosystem

This aim is addressed through findings in Chapter 5 and Chapter 7. Chapter 5 identifies factors that foster sustainability within STPs, emphasizing the importance of strategic planning for a resilient entrepreneurial ecosystem. Chapter 7 complements this by employing big data analytics and econometric models to simulate sustainable growth pathways for high-value tech entrepreneurship, with implications for regional policy and ecosystem management. These findings contribute directly to establishing a sustainable model for tech entrepreneurship within STPs.

1.2.4 Investigate Effective Approaches for Technology Transfer in Entrepreneurial Environments

This objective is comprehensively addressed in Chapter 6, where the study examines the role of Technology Transfer Offices (TTOs) and compares different management models for optimizing technology transfer processes. The findings highlight how hierarchical and ambidextrous team structures within TTOs affect commercialization outcomes, proposing effective frameworks for technology transfer within entrepreneurial universities. This chapter's insights are aligned with the aim of advancing effective technology transfer approaches in STP-linked environments.

1.2.5 Investigate Innovation Pathways and Economic Outcomes of Knowledge Producers

Chapter 7 addresses this objective by conducting a longitudinal analysis of state-funded firms using data from the UK's Gateway to Research (GtR) database. This chapter assesses financial performance differentials between funded and control firms, examining the impacts of SIC codes and geographical factors on outcomes. The analysis identifies universities linked to superior economic performance, providing valuable insights into optimizing knowledge transfer pathways and achieving economic benefits.

8.3 Limitations of the study

This study provides important findings about the growth patterns and potential of small and medium-sized science and technology parks, with a focus on their ability to attract larger partners and foster expansion. Nevertheless, certain challenges related to methodology, scope, and applicability arose during the course of this research.

8.3.1 Methodological limitations

A methodological constraint is the reliance on panel data pertaining specifically to Swedish Standard Industrial Classification (SNI) companies within the industrial code ‘J 62’ (programming and related industries). Although this offers detailed insights into the computing, Internet, and e-commerce sectors, it restricts the applicability of the findings to other industries. Additionally, this study utilised Euclidean distances to measure proximity, which may introduce artefacts in metropolitan settings, where firm density is high. While time distances were considered negligible owing to the small geographic areas, future studies may benefit from incorporating time distance measures to more accurately account for urban traffic patterns and other real-world conditions.

8.3.2 Limited geographic and contextual scope of findings

This research investigates small and medium-sized STPs situated in specific municipalities in Sweden, such as Skövde and Umeå. The geographical and contextual specificities of this study restrict the applicability of the findings to other regions or countries with varying industrial bases, government policies, and economic conditions. For example, the economic health and growth patterns observed in Swedish science parks may not be directly applicable to STPs in countries with less-developed industrial infrastructure or different regulatory environments.

8.3.3 Data availability and completeness

One of the limitations in the analysis of STPs is the scarcity of data on unsuccessful or bankrupt STPs. This information is vital for understanding the factors that contribute to STP failure. The absence of such data may result in biased analysis, as it focuses primarily on active STPs, neglecting the challenges and pitfalls that new struggling or bankrupt STPs may encounter. It is essential to conduct longitudinal studies to track the performance of STPs over time, including those that do not achieve success.

Research addressing these limitations involves expanding the scope to include a wider range of industries and locations. A mixed-methods approach combining quantitative data with qualitative insights from interviews and case studies can provide a deeper understanding of the STP dynamics. Advanced spatial analysis techniques and real-time distance measurements may enhance the accuracy of proximity-related findings. While this study contributes significantly to the understanding of STP growth, acknowledging these limitations is essential for advancing the field and guiding effective global policies and strategies for STP development.

8.4 Recommendations for Future Research

A range of research directions is proposed to advance understanding and address the limitations identified in this study. It is advised that future research should broaden its scope beyond the computing and e-commerce industries to encompass other high-tech sectors, such as biotechnology and renewable energy, in order to deliver more comprehensive insights into the effects of science and technology parks (STPs) across diverse sectors. Additionally, comparative investigations of STPs in various countries would aid in identifying common and context-specific success factors. It is also recommended that longitudinal studies tracking the development trajectories of STPs, including those that fail or stagnate, are essential for comprehending the critical factors influencing both success and failure. Analysing the consequences of technological shifts and economic disruptions on STPs would further illuminate their resilience and adaptability. Future research should refine the Triple Helix model by incorporating variables, such as asset specificity and the spatial distribution of companies around STPs, making it more relevant to contemporary settings.

Research should also examine the applicability of the model across different sectors and types of universities. Moreover, comparative evaluations of Technology Transfer Office (TTO) management models across universities of diverse sizes and specialisations can identify the best practices for technology transfer. Additionally, research can explore the role of ambidexterity within TTOs and its impact on innovation outcomes. Collecting data from user surveys at the university level can provide valuable insights into TTO structures, participation, and performance. Assessing the organisational structures of TTOs across universities aids in identifying how structural variations affect their efficiency in managing technology transfers. By evaluating stakeholder engagement, surveys reveal how collaboration quality within these offices influences the performance and success of technology transfer initiatives. Moreover, gathering data on performance indicators, such as successful transfers, commercialisation rates, and researcher and industry partner satisfaction, provides a comprehensive perspective on TTO effectiveness. Surveys also examine how TTOs balance innovative exploration with practical application, highlighting the impact of this equilibrium on their success and adaptability.

Finally, establishing a database of failed and bankrupt STPs and devising predictive models for failure based on factors such as firm composition and management practices would offer essential knowledge for risk management in STPs. These recommendations aim to address the current study's limitations and guide future research toward a deeper understanding of the factors contributing to the success and sustainability of Science and Technology Parks.

In summary, this research adds to the expanding body of knowledge on science and technology park development by providing a refined perspective on the relationship between innovation, organisational behaviour, and regional economic development. The suggested preliminary model for the founding and development of STPs can serve as a useful guide for policymakers and practitioners aiming to cultivate sustainable high-tech entrepreneurship ecosystems. This study highlights that the structure of technology transfer functions in universities and the pathways through which knowledge is transferred to industries play essential roles in determining the success of innovation and economic outcomes. The findings indicate that large universities should establish cooperative team structures in their technology transfer offices (TTOs) to maximise productivity. Implementing an ambidextrous management architecture within a Technology Transfer Office (TTO) enhances decision-making and innovation. This involves evaluating the hierarchical, cooperative, and hybrid models. In hierarchical management, centralised decision-making with a top-down approval process minimises risks, but it can also slow innovation. In cooperative management, peer collaboration, where decisions are collectively made, fosters creativity but can be costly if poor decisions are endorsed. Finally, hybrid management combines hierarchical and cooperative approaches, adapting to the situation for optimal decision-making. A hybrid model is often the most effective for balancing control and innovation. Each model has its own strengths and weaknesses, and its choice depends on the context and staff capabilities. Integrating all three elements can foster a dynamic and innovative technology transfer office environment.

Based on the research and analysis undertaken, a novel diagram (see figure 6.4) was devised that illustrates the optimal intersection where both asset specificity and degree of ambidexterity are elevated. This diagram also posits that mature universities are characterised by significant research income. The data on research income were sourced from the "Higher Education

Statistics Agency" website (HESA, 2024), covering the period from 2016 to 2023 for the top 100 universities.

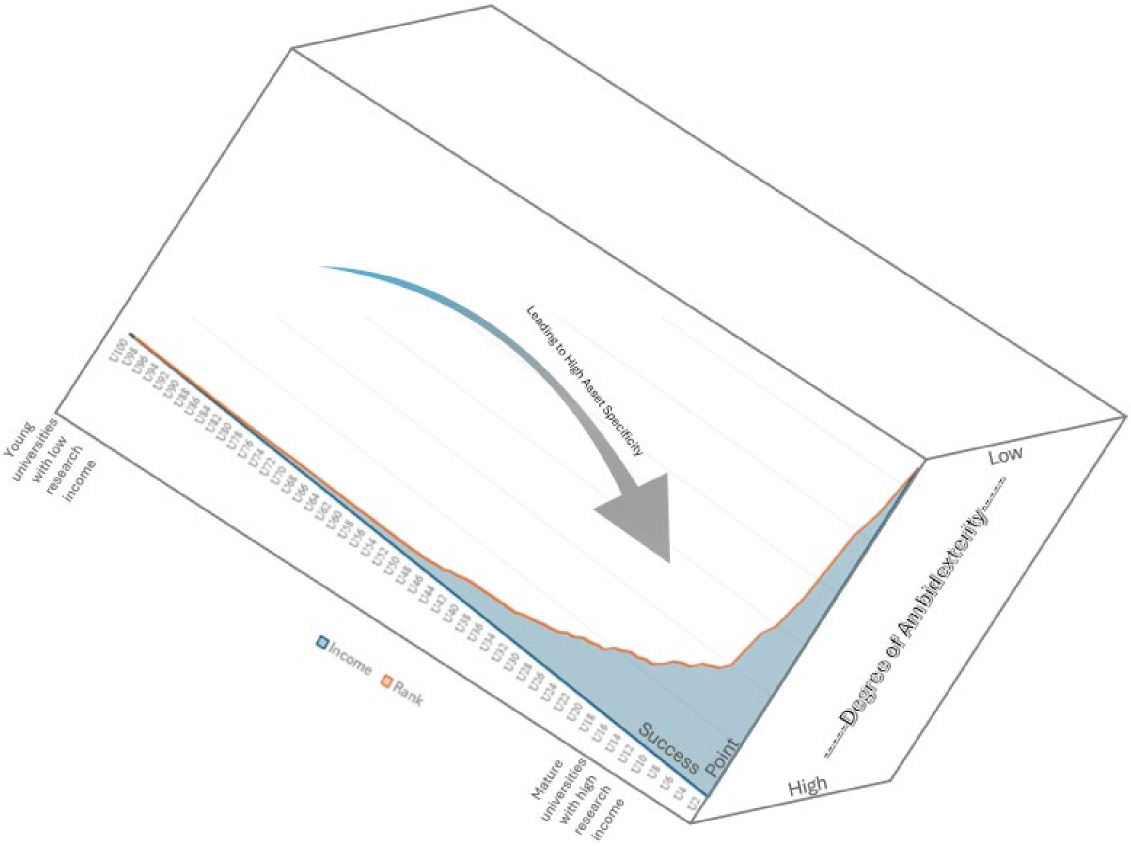


Figure 6.4: Factors in the success of university technology transfer offices (Author’s own figure)

This figure 6.4 identifies a distinct "Success Point”, representing an ideal equilibrium where universities can maximise their potential for success in technology transfer and related endeavours. The diagram includes an arrow labelled ‘Leaning to High Asset Specificity’ indicating a trend in which universities progressively transition from lower to higher asset specificity as their research income improves. This suggests that as universities become more established and financially robust, they increasingly focus on specialised assets. In summary, the diagram posits that younger universities with lower research incomes typically exhibit lower ambidexterity. Conversely, as universities mature and their research income increases, they tend to improve in ambidexterity. The "Success Point" signifies the juncture at which universities achieve an optimal balance of high asset specificity and ambidexterity, a balance potentially critical for their sustained success and ability to effectively leverage their technology transfer offices. Future research should continue to explore these topics using detailed data and comprehensive analyses to enhance our understanding of effective knowledge transfers and their economic benefits.

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10 Appendix

Appendix Table 10.1: The spectrum of SIC codes of firms involved in AHRC and Innovate UK projects and their descriptions (Mondal and Mellor, 2024).

SIC Code	Activity	SIC Code	Activity
01110	Growing of cereals (except rice), leguminous crops and oil seeds	29310	Manufacture of electrical and electronic equipment for motor vehicles and their engines
01130	Growing of vegetables and melons, roots and tubers	29320	Manufacture of other parts and accessories for motor vehicles
01190	Growing of other non-perennial crops	30110	Building of ships and floating structures
01410	Raising of dairy cattle	30120	Building of pleasure and sporting boats
01470	Raising of poultry	30300	Manufacture of air and spacecraft and related machinery
01500	Mixed farming	30400	Manufacture of military fighting vehicles
01610	Support activities for crop production	30920	Manufacture of bicycles and invalid carriages
01629	Support activities for animal production (other than farm animal boarding and care) n.e.c.	31030	Manufacture of mattresses
01640	Seed processing for propagation	32500	Manufacture of medical and dental instruments and supplies
03210	Marine aquaculture	32990	Other manufacturing n.e.c.
08120	Operation of gravel and sand pits; mining of clays and kaolin	33150	Repair and maintenance of ships and boats
09100	Support activities for petroleum and natural gas extraction	36000	Water collection, treatment and supply
10110	Processing and preserving of meat	38210	Treatment and disposal of non-hazardous waste
10130	Production of meat and poultry meat products	41100	Development of building projects
10200	Processing and preserving of fish, crustaceans and molluscs	41201	Construction of commercial buildings
10390	Other processing and preserving of fruit and vegetables	42220	Construction of utility projects for electricity and telecommunications
10420	Manufacture of margarine and similar edible fats	43210	Electrical installation
10511	Liquid milk and cream production	43999	Other specialised construction activities n.e.c.
10611	Grain milling	46110	Agents selling agricultural raw materials, livestock, textile raw materials and semi-finished goods
10710	Manufacture of bread; manufacture of fresh pastry goods and cakes	46130	Agents involved in the sale of timber and building materials
10720	Manufacture of rusks and biscuits; manufacture of preserved pastry goods and cakes	46210	Wholesale of grain, unmanufactured tobacco, seeds and animal feeds
10850	Manufacture of prepared meals and dishes	46310	Wholesale of fruit and vegetables
10890	Manufacture of other food products n.e.c.	46690	Wholesale of other machinery and equipment
10910	Manufacture of prepared feeds for farm animals	46720	Wholesale of metals and metal ores
11050	Manufacture of beer	46750	Wholesale of chemical products
13200	Weaving of textiles	47610	Retail sale of books in specialised stores
13960	Manufacture of other technical and industrial textiles	49200	Freight rail transport
13990	Manufacture of other textiles n.e.c.	49319	Other urban, suburban or metropolitan passenger land transport (not underground, metro or similar)
19201	Mineral oil refining	49410	Freight transport by road
20110	Manufacture of industrial gases	52103	Operation of warehousing and storage facilities for land transport activities
20120	Manufacture of dyes and pigments	58130	Publishing of newspapers
20130	Manufacture of other inorganic basic chemicals	58290	Other software publishing
20140	Manufacture of other organic basic chemicals	59111	Motion picture production activities
20150	Manufacture of fertilizers and nitrogen compounds	59120	Motion picture, video and television programme post-production activities
20160	Manufacture of plastics in primary forms	59133	Television programme distribution activities
20200	Manufacture of pesticides and other agrochemical products	59140	Motion picture projection activities
20301	Manufacture of paints, varnishes and similar coatings, mastics and sealants	61200	Wireless telecommunications activities
20590	Manufacture of other chemical products n.e.c.	61900	Other telecommunications activities
20600	Manufacture of man-made fibres	62011	Ready-made interactive leisure and entertainment software development
21100	Manufacture of basic pharmaceutical products	62012	Business and domestic software development

21200	Manufacture of pharmaceutical preparations	62020	Information technology consultancy activities
22210	Manufacture of plastic plates, sheets, tubes and profiles	62090	Other information technology service activities
22220	Manufacture of plastic packing goods	64209	Activities of other holding companies n.e.c.
22290	Manufacture of other plastic products	68209	Other letting and operating of own or leased real estate
23120	Shaping and processing of flat glass	70100	Activities of head offices
23320	Manufacture of bricks, tiles and construction products, in baked clay	70229	Management consultancy activities other than financial management
23490	Manufacture of other ceramic products n.e.c.	71121	Engineering design activities for industrial process and production
23610	Manufacture of concrete products for construction purposes	71122	Engineering related scientific and technical consulting activities
24320	Cold rolling of narrow strip	71129	Other engineering activities
24510	Casting of iron	72110	Research and experimental development on biotechnology
24530	Casting of light metals	72190	Other research and experimental development on natural sciences and engineering
25110	Manufacture of metal structures and parts of structures	72200	Research and experimental development on social sciences and humanities
25290	Manufacture of other tanks, reservoirs and containers of metal	73110	Advertising agencies
25500	Forging, pressing, stamping and roll-forming of metal; powder metallurgy	74100	Specialised design activities
25610	Treatment and coating of metals	74209	Photographic activities not elsewhere classified
25620	Machining	74901	Environmental consulting activities
25730	Manufacture of tools	74909	Other professional, scientific and technical activities n.e.c.
25930	Manufacture of wire products, chain and springs	77320	Renting and leasing of construction and civil engineering machinery and equipment
25940	Manufacture of fasteners and screw machine products	77390	Renting and leasing of other machinery, equipment and tangible goods n.e.c.
25990	Manufacture of other fabricated metal products n.e.c.	82110	Combined office administrative service activities
26110	Manufacture of electronic components	82990	Other business support service activities n.e.c.
26120	Manufacture of loaded electronic boards	84220	Defence activities
26200	Manufacture of computers and peripheral equipment	85100	Pre-primary education
26309	Manufacture of communication equipment other than telegraph, and telephone apparatus and equipment	85520	Cultural education
26511	Manufacture of electronic measuring, testing etc. equipment, not for industrial process control	85590	Other education n.e.c.
26512	Manufacture of electronic industrial process control equipment	85600	Educational support services
26701	Manufacture of optical precision instruments	86101	Hospital activities
26702	Manufacture of photographic and cinematographic equipment	86210	General medical practice activities
27110	Manufacture of electric motors, generators and transformers	86900	Other human health activities
27120	Manufacture of electricity distribution and control apparatus	87300	Residential care activities for the elderly and disabled
27200	Manufacture of batteries and accumulators	88990	Other social work activities without accommodation n.e.c.
27310	Manufacture of fibre optic cables	90010	Performing arts
27320	Manufacture of other electronic and electric wires and cables	90020	Support activities to performing arts
27900	Manufacture of other electrical equipment	90030	Artistic creation
28120	Manufacture of fluid power equipment	90040	Operation of arts facilities
28131	Manufacture of pumps	91011	Library activities
28150	Manufacture of bearings, gears, gearing and driving elements	91020	Museums activities
28250	Manufacture of non-domestic cooling and ventilation equipment	91030	Operation of historical sites and buildings and similar visitor attractions
28302	Manufacture of agricultural and forestry machinery other than tractors	93210	Activities of amusement parks and theme parks
28490	Manufacture of other machine tools	93290	Other amusement and recreation activities n.e.c.
28910	Manufacture of machinery for metallurgy	94120	Activities of professional membership organizations
28930	Manufacture of machinery for food, beverage and tobacco processing	94990	Activities of other membership organizations n.e.c.

28990	Manufacture of other special-purpose machinery n.e.c.	96090	Other service activities n.e.c.
29100	Manufacture of motor vehicles	99000	Activities of extraterritorial organizations and bodies
29201	Manufacture of bodies (coachwork) for motor vehicles (except caravans)		

Appendix Table 10.2: Overview of keys, universities, firms, firms distance (Km) in straight line (Euclidean distances) from project leader, and firm SIC codes. AHRC denotes funded by AHRC and InnoUK denotes funded by Innovate UK.

Projects	University	Firms	SIC Codes	Distance KM (HEI project lead to Firms)	Projects	University	Firms	SIC Codes	Distance KM (HEI project lead to Firms)
AHRC1	3	1	91011	119.37	InnoUK71	1	1	73110	593.01
AHRC2	1	1	90030	278.71	InnoUK72	2	1	86210	30.69
AHRC3	1	1	90030	224.58	InnoUK73	1	1	71129	51.90
AHRC4	1	1	86900	390.22	InnoUK74	1	1	25990	1.54
AHRC5	1	1	94990	392.87	InnoUK75	4	1	72110	135.23
AHRC6	1	1	85590	8.98	InnoUK76	1	1	22290	6.26
AHRC7	2	1	93290	287.23	InnoUK77	1	1	72190	207.47
AHRC8	4	1	90040	224.98	InnoUK78	1	2	36000 42220	124.09 132.17
AHRC9	1	1	88990	70.94	InnoUK79	1	1	36000	4.74
AHRC10	1	1	91020	309.42	InnoUK80	1	2	25730 30300	25.76 193.65
AHRC11	3	1	91011	54.57	InnoUK81	1	1	32990	57.81
AHRC12	1	1	88990	191.52	InnoUK82	1	1	30300	120.40
AHRC13	1	1	72190	142.09	InnoUK83	2	1	25620	157.62
AHRC14	3	1	87300	171.44	InnoUK84	1	2	01110 46110	235.92 74.13
AHRC15	3	1	90030	72.91	InnoUK85	2	5	25610 25990 30300 30300 26110	117.75 36.28 119.94 195.39 120.72
AHRC16	1	1	90030	86.56	InnoUK86	1	1	10890	63.62
AHRC17	2	1	74909	225.43	InnoUK87	2	1	30400	84.17
AHRC18	1	1	90020	144.97	InnoUK88	1	1	84220	191.72
AHRC19	3	1	86900	269.91	InnoUK89	1	2	29320 31030	146.91 4.50
AHRC20	1	1	59140	0.42	InnoUK90	1	1	28150	14.72
AHRC21	7	1	74909	75.41	InnoUK91	1	2	28150 71122	14.71 66.13
AHRC22	23	3	74909 90030 87300	225.32 258.64 258.69	InnoUK92	1	1	10850	270.73
AHRC23	1	1	90010	103.10	InnoUK93	4	1	72110	135.23
AHRC24	1	1	91020	84.96	InnoUK94	1	1	26200	549.10
AHRC25	3	1	87300	216.17	InnoUK95	1	1	96090	137.87
AHRC26	17	2	94120 90030	259.85 324.05	InnoUK96	1	2	29320 27900	273.89 5.75
AHRC27	4	1	74909	106.85	InnoUK97	1	1	26110	268.42
AHRC28	1	1	90010	15.18	InnoUK98	1	1	20140	82.34
AHRC29	3	1	87300	216.17	InnoUK99	1	2	01610 46310	182.50 147.28
AHRC30	1	1	85590	171.65	InnoUK100	1	1	25500	248.16
AHRC31	6	1	90010	95.22	InnoUK101	2	1	32500	364.07
AHRC32	1	1	96090	53.68	InnoUK102	1	1	32990	50.80

AHRC33	3	1	72190	101.76	InnoUK103	1	1	20200	149.96
AHRC34	1	1	88990	174.36	InnoUK104	1	2	28930 70100	131.08 7.24
AHRC35	1	1	90040	23.83	InnoUK105	1	1	27900	5.76
AHRC36	1	2	90020 90020	6.46 4.56	InnoUK106	1	1	30300	193.65
AHRC37	1	1	90020	5.28	InnoUK107	1	1	71129	126.85
AHRC38	2	1	88990	4.45	InnoUK108	1	1	62090	35.89
AHRC39	2	2	82110 85590	138.29 41.29	InnoUK109	1	2	10390 10890	348.18 231.84
AHRC40	1	1	87300	0.49	InnoUK110	1	1	26512	128.46
AHRC41	2	1	91020	166.64	InnoUK111	1	2	96090 28990	74.54 108.89
AHRC42	2	1	85590	6.65	InnoUK112	2	1	86101	225.43
AHRC43	6	1	85590	82.83	InnoUK113	2	4	22290 20130 32990 25940	42.52 196.42 103.34 7.28
AHRC44	4	1	72190	240.38	InnoUK114	1	1	96090	137.87
AHRC45	2	1	90020	152.25	InnoUK115	1	1	62020	396.88
AHRC46	1	2	85100 85600	59.45 109.07	InnoUK116	2	1	49200	5.64
AHRC47	2	1	94120	0.46	InnoUK117	2	3	01470 10910 20590	72.93 70.40 115.56
AHRC48	1	1	85590	3.84	InnoUK118	1	2	26120 43999	61.88 98.53
AHRC49	3	1	70100	201.91	InnoUK119	1	1	24530	32.15
AHRC50	4	1	87300	88.61	InnoUK120	1	1	20590	50.98
AHRC51	1	1	94990	243.16	InnoUK121	1	1	01629	507.45
AHRC52	6	2	91030 87300	101.47 88.60	InnoUK122	1	2	72190 26511	87.80 84.69
AHRC53	1	1	90030	32.88	InnoUK123	1	1	46310	48.84
AHRC54	1	1	85590	185.88	InnoUK124	1	2	27900 32990	144.26 407.43
AHRC55	1	1	85520	5.45	InnoUK125	1	1	96090	137.87
AHRC56	2	1	90020	306.41	InnoUK126	1	1	28250	124.36
AHRC57	6	1	99000	75.26	InnoUK127	1	1	13960	12.79
AHRC58	1	1	90040	3.29	InnoUK128	2	1	20200	212.75
AHRC59	9	8	90030 85520 85590 90010 90020 85520 90010 26200	10.62 6.14 0.98 5.12 5.28 2.32 1.536 104.20	InnoUK129	1	1	72110	245.24
AHRC60	7	1	90030	345.15	InnoUK130	1	2	59120 26702	43.70 43.82
AHRC61	4	1	72190	149.49	InnoUK131	1	1	30300	120.40
AHRC62	2	1	91011	35.78	InnoUK132	2	1	26110	215.45
AHRC63	6	1	85520	44.80	InnoUK133	1	2	27110 84220	120.45 309.51
InnoUK1	1	2	24320 32990	128.84 187.18	InnoUK134	1	1	70100	24.57
InnoUK2	1	1	01110	104.01	InnoUK135	1	1	10910	72.73
InnoUK3	2	1	01629	335.47	InnoUK136	1	2	13200 26511	239.28 175.73
InnoUK4	1	1	29320	213.23	InnoUK137	1	2	20130 25290	129.98 129.98
InnoUK5	1	1	26110	259.28	InnoUK138	1	1	71122	504.92
InnoUK6	1	2	84220 26110	375.06 282.17	InnoUK139	1	2	72190 26110	216.42 171.90

InnoUK7	1	1	10390	258.53	InnoUK140	1	2	59133 62012	210.35 29.90
InnoUK8	1	2	22290 32990	314.92 232.83	InnoUK141	1	2	01629 74909	287.84 246.34
InnoUK9	1	1	21100	137.48	InnoUK142	1	1	26110	215.45
InnoUK10	1	1	72190	310.76	InnoUK143	1	1	13960	12.79
InnoUK11	1	1	25990	214.35	InnoUK144	1	1	96090	34.54
InnoUK12	1	1	74909	70.99	InnoUK145	1	2	62020 96090	113.23 18.53
InnoUK13	1	1	10720	273.08	InnoUK146	1	1	21100	116.63
InnoUK14	1	1	72110	276.65	InnoUK147	1	1	62012	1.28
InnoUK15	1	1	29100	110.03	InnoUK148	1	1	32990	161.42
InnoUK16	1	1	03210	572.63	InnoUK149	1	2	28150 29320	241.25 46.45
InnoUK17	1	1	28990	590.39	InnoUK150	3	1	82990	57.10
InnoUK18	1	1	72190	258.19	InnoUK151	2	1	62012	9.85
InnoUK19	1	1	96090	162.70	InnoUK152	1	2	72110 22210	381.70 334.09
InnoUK20	1	1	32990	267.26	InnoUK153	1	1	70100	149.09
InnoUK21	1	2	22290 82990	19.93 4.32	InnoUK154	2	6	96090 10890 10390 11050 46310 70100	172.29 169.44 84.53 31.94 189.94 56.03
InnoUK22	1	2	29320 29100	131.70 273.86	InnoUK155	1	1	32990	230.35
InnoUK23	1	1	96090	157.91	InnoUK156	1	3	20590 82990 24510	218.54 62.56 171.38
InnoUK24	1	1	72110	345.53	InnoUK157	3	4	29320 27900 32990 71122	94.34 73.46 105.32 89.78
InnoUK25	1	3	01130 72190 27900	42.91 194.00 133.69	InnoUK158	2	1	20301	367.92
InnoUK26	1	1	19201	176.04	InnoUK159	1	2	32990 10710	424.77 283.36
InnoUK27	1	1	82990	86.95	InnoUK160	1	3	24530 70100 20590	32.15 25.42 113.93
InnoUK28	1	2	42220 96090	287.23 91.49	InnoUK161	2	1	26110	41.58
InnoUK29	1	1	27900	216.87	InnoUK162	1	1	70100	165.57
InnoUK30	1	1	61900	212.73	InnoUK163	1	1	20160	276.65
InnoUK31	3	2	26110 26309	61.15 43.00	InnoUK164	1	1	27320	107.02
InnoUK32	1	1	25610	112.55	InnoUK165	1	1	26110	152.58
InnoUK33	1	1	28150	14.72	InnoUK166	1	2	26512 32990	165.29 47.29
InnoUK34	1	1	72190	4.02	InnoUK167	4	1	72110	135.23
InnoUK35	2	3	01629 28302 74909	359.36 203.44 356.65	InnoUK168	1	2	22210 20600	32.545 54.418
InnoUK36	3	2	28150 20590	78.10 230.62	InnoUK169	1	1	72190	227.28
InnoUK37	2	1	26110	120.72	InnoUK170	1	2	82990 10890	328.98 225.41
InnoUK38	1	1	71121	6.86	InnoUK171	1	2	96090 74909	290.62 609.94
InnoUK39	1	1	28120	221.66	InnoUK172	2	1	22220	182.04
InnoUK40	1	1	26110	2.11	InnoUK173	1	1	26110	267.84
InnoUK41	1	1	20200	149.62	InnoUK174	1	1	72190	85.20

InnoUK42	1	1	74909	91.47	InnoUK175	1	2	29320 22290	138.19 203.04
InnoUK43	1	1	27900	18.64	InnoUK176	3	1	46110	425.87
InnoUK44	1	1	74901	108.63	InnoUK177	1	1	96090	155.37
InnoUK45	1	1	26511	45.76	InnoUK178	3	2	26512 72190	190.88 236.08
InnoUK46	1	2	49410 52103	105.14 167.86	InnoUK179	2	1	20590	192.38
InnoUK47	1	1	26702	239.70	InnoUK180	1	1	72190	195.17
InnoUK48	1	1	72190	47.77	InnoUK181	1	3	32990 20590 22290	407.43 244.19 269.94
InnoUK49	1	2	46310 46310	207.06 266.16	InnoUK182	2	3	32990 27200 71122	157.04 82.06 109.37
InnoUK50	1	1	84220	209.73	InnoUK183	1	2	71121 90030	83.36 25.60
InnoUK51	1	1	32990	282.99	InnoUK184	1	2	71122 30120	110.16 204.94
InnoUK52	1	1	46690	243.80	InnoUK185	1	1	74100	65.95
InnoUK53	1	1	08120	304.30	InnoUK186	1	1	28150	14.72
InnoUK54	1	1	27900	53.72	InnoUK187	4	1	72110	135.23
InnoUK55	1	3	28150 26110 26110	192.91 23.18 60.57	InnoUK188	2	3	10420 01410 10110	305.53 188.36 234.77
InnoUK56	1	2	32990 33150	25.66 3.62	InnoUK189	1	1	26512	203.94
InnoUK57	1	1	72190	151.50	InnoUK190	1	2	74909 62090	282.84 272.22
InnoUK58	1	1	85590	290.75	InnoUK191	1	1	46110	105.89
InnoUK59	1	1	82110	34.33	InnoUK192	2	3	72190 96090 27900	120.11 178.22 53.72
InnoUK60	1	1	10850	20.26	InnoUK193	1	4	27110 27110 26110 29100	265.82 4.43 207.87 325.55
InnoUK61	1	1	20140	9.76	InnoUK194	1	2	28150 29100	138.60 134.71
InnoUK62	1	1	70100	181.22	InnoUK195	1	1	72110	276.65
InnoUK63	1	1	22290	146.65	InnoUK196	1	1	62090	30.44
InnoUK64	1	2	26512 30300	28.66 70.33	InnoUK197	1	3	74909 71122 41100	56.77 13.89 104.69
InnoUK65	1	1	26512	28.66	InnoUK198	1	1	72190	102.55
InnoUK66	1	1	96090	90.54	InnoUK199	1	1	23120	101.51
InnoUK67	2	1	26309	215.09	InnoUK200	1	1	32500	364.07
InnoUK68	1	1	01629	111.95	InnoUK201	1	1	72190	14.21
InnoUK69	1	2	71122 26110	333.28 311.96	InnoUK202	1	2	72200 72190	1.84 25.84
InnoUK70	1	1	96090	155.37	InnoUK203	1	1	82990	135.70

11 Glossary and Definitions

Entrepreneurial University - An institution that fosters entrepreneurship through innovation, partnerships, and practical experience, aiming to drive economic and social impact.

Fuzzy Expert Systems - Computer systems that use fuzzy logic to handle imprecise or uncertain information, simulating human decision-making.

GARCH models - Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models are used in econometrics and finance to analyse and forecast the volatility of time series data

Geographic Clustering - The concentration of businesses or institutions in a specific location to enhance collaboration, efficiency, and innovation.

Innovation - The process of creating and applying new ideas, methods, or products to improve or solve problems, leading to significant advancements or improvements.

Innovation Clusters - Geographic concentrations of interconnected businesses, research institutions, and support organizations that drive innovation and economic growth.

Intellectual Property - Legal rights granted for creations of the mind, such as inventions, trademarks, and copyrights, protecting the creator's exclusive use.

Knowledge Economy - An economic system where growth is driven by the creation, distribution, and use of knowledge and information rather than traditional industries.

Societal Benefit - The positive impact or advantage that an action, policy, or innovation provides to society as a whole.

Spatial Structure - The arrangement and organization of physical and functional elements within a given space or region.

Technological Districts - Geographical areas where technology-focused businesses, research institutions, and support organizations are clustered to foster innovation and economic growth.

Technological Entrepreneurial Ecosystem - A network of interconnected organizations and resources that support and drive technology-based start-ups and innovation.

Triple Helix - A model of innovation involving the collaboration between academia, industry, and government to drive economic development and technological advancement.