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Developing Young Science and Technology Parks: Recent Findings from Industrial Nations Using the Data-Driven Approach

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Abstract: Science and technology parks (STPs) are curated locations where new technology-based firms (NTBFs) and other SMEs and firms can conglomerate and promote a culture of innovation. Overall, the aim is to construct a sustainable high-value tech entrepreneurship ecosystem, and to this end we present here some recent and novel concepts derived from approaches using a data-driven statistical foundation. This paper considers studies on the organic growth of young start-up science and technology parks by authors who have used big data, econometric analyses, panel data and computer simulations. The results and concepts are derived from industrialized countries, notably Sweden and the UK, and may well be applicable to many regions and emerging economies. The findings are of interest to regional development, technology entrepreneurs considering choosing an STP to inhabit, as well as those in STP central teams, specializing in management and enterprise development, including the sustainable growth of new parks.

Keywords: science and technology parks; regional planning; science growth; economic development; decision making; triple helix model

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1. Introduction

Lim et al. [1] studied science and technology parks (STPs), linking improvements in public infrastructure to sustainable improvements not only in environmental quality but also in working environments and business ecosystems. However, a number of paradoxes become apparent when discussing STPs. Firstly, the establishment of STPs—and thus the lead-in to an expected innovative new 'knowledge economy'—is particularly attractive to structure-weak regions due to the promise of the contribution of the STP to the regional economy and development (see for example, [2,3], who present recent reviews). Despite this vision and state support, only about ~20% of STPs are sustainably successful (for global figures, see [4,5], and for the UK, see [6]).

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 industrialized 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' approximately began 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 [7].

The major theory behind the concept of STPs is the triple helix [8], which led to the present model of STP development [9]. Recently the triple helix model was criticised by [10] as being too imprecise for use in regional planning. Authors such as Perkmann et al. [11], 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 [12] 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 [13], and it is suggested that recent effects of decentralizing 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 [14] and Will et al. [15] showed that innovations can have a negative value. Secondly, as proposed by Nobel laureate Joseph Stiglitz, the organizational 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 [16], often in conjunction with big data (e.g., [17]), panel data (e.g., [18]) and Geographic Information Systems (GIS). GIS have been used for studies on STPs by [19] and by [20]. Other allied approaches including a hybrid MCDM analysis [1] have also been reported.

2. A Theoretical Base

According to the innovation-based theory of the firm [21,22], 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 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.

2.1. Critique of STPs Role in the Regional Economy

Using the pharmaceutical sector in the UK as an example, Mondal et al. [20] reported that a local population of >20 specialized firms are required to support a start-up STP, and that specialized SPTs need a distance of >33 km from the next competitor, although they can be as little as 12 km from non-specialized SPTs with whom they are not in direct competition [20].

Kussainov et al. [19] measured firm density around several UK STPs and found that for IT-specializing STPs and firms, as well as biotech-specializing STPs and firms, the firms formed an annular ring 4–7 km around the STP.

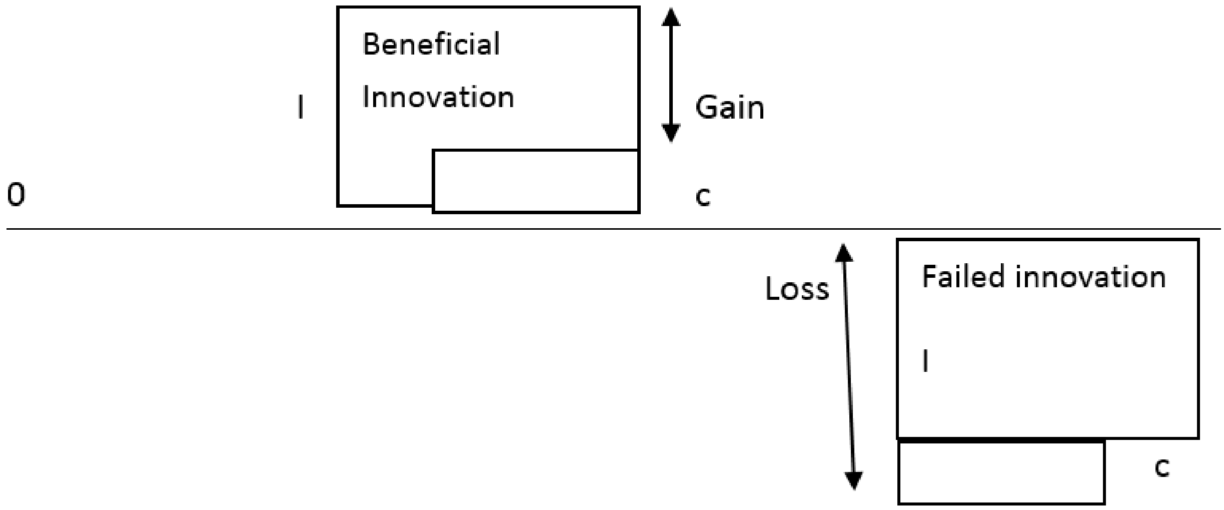


Figure 1. Effects of adopting good-fit and poor-fit innovations. The financial effects of a beneficial innovation ("Gain") is 'I' minus 'c', where 'I' represents the value of the innovation and 'c' represents the costs of implementing the innovation. This can be represented by [I minus c]. If the innovation is poor-fit, the loss is [minus (I plus c)], and is a larger amount than "Gain" (taken from [14]).

Mondal et al. [20] also reported that UK universities scoring highly in pharmaceutical sciences did not attract firms specializing in pharmaceutical sciences, nor STPs specializing in pharmaceutical sciences, to their locality. The same authors reported that on-campus STPs were not significantly better at attracting firms specializing in pharmaceutical sciences than off-campus STPs [20]. Focusing on this topic, two recent papers assessed the entrepreneurial knock-on effects from academia; Vaninoa et al. [23] examined research grants using the UK Gateway to Research database and found a positive correlation, while another study [24] surveyed the EU countries using very large panel datasets, finding no correlation. This may show some limitations to a 'Big Data' approach because Johnston [25] as well as Audretsch and Belitski [26] stressed that university–industry co-operation depends on factors that include social as well as technological and organisational proximity, while Radko et al. [27] emphasised the organisational architecture across different stages of entrepreneurship and different profiles of the universities involved. Clearly, 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 [23] and [24] demonstrates that "Big Data" approaches are too coarse-grained and that case studies, as communicated by [27], on successful tech transfer departments will reveal more.

The results presented here should be taken into consideration regarding establishing STPs as a part of a regional development strategy; high-tech STPs are clearly of more value to the nation than simple business clusters [28]. While simple business clusters may occasionally be what is required, the above criteria should enable planners to manage expectations.

2.2. *Critique of the Triple Helix*

Al-Maadeed and Weerakkody [29] pointed out that in the 'classical' triple helix theory [8], the knowledge-based economy generates scientific and technological innovation, and thus leads to the generation of national economic wealth. However, the order in which in functions of the triple helix are initiated is not well addressed in the present context of the triple helix theory. Examples of where this theory performs poorly are pressing externalities such as COVID-19 (e.g., the NTBFs BioNTech and Pfizer), while others can be industry-led (e.g., Space X). This variable initiation point is a problem for the classical view (e.g., [9]) of

STP development, which envisages mainly university spin-outs (or possibly other high-tech firms) as starting points, resorting at some subsequent stage back to university research labs for more intellectual input. Another aspect often mentioned is the recruitment of graduates, albeit that these graduates are highly mobile.

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 [14,15].
B. Intellectual input into university–business co-operation is infrequent due to narrow asset specificity, as reported by [30–32].
C. Post-COVID-19 appreciation of new sets of technology means that firms can make a move from STP premisses to adjoining locales [19], 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., [9]), may well need updating.

3. STP Development

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 [18,33]. 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 [33].

As an STP grows, poor decisions will inevitably become more and more costly, and to avoid a market failure (see Figure 2) may force a high-tech STP to re-focus into a lower-tech area, e.g., hosting general businesses, incubator services, etc. [34]. 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 [35]. To do this, the young STP should become a focus of innovation that can attract larger firms interested in new ideas, fresh talent and take-overs [36]. 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 organizations are included in the process [34]; 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 [37], 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 [37].

Figure 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 [38]. Even with 400 on-cluster firms, Figure 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 [39,40]. The work of [40] 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 & Aquisitions, etc. [2].

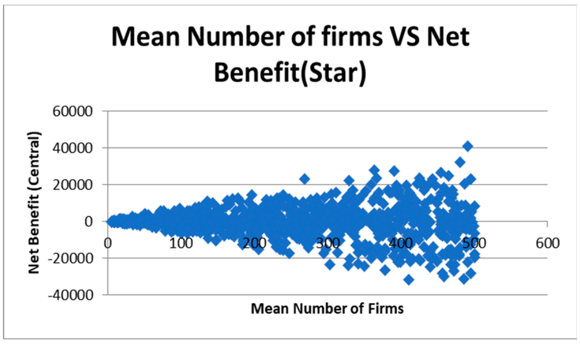
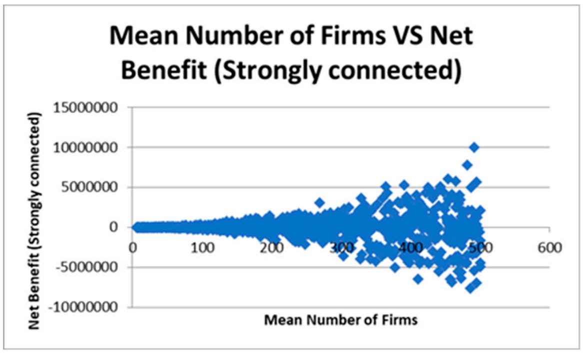
Stage	SEM	Plot
A: Early Stage STP, "Star" topology	$\pi = \sum_{j=2}^{N} (B_{1,j} - C_{1,j}),$	
B: Late Stage STP including ambidextrous connections between on-STP firms	$\pi = \sum_{i=1,j=1}^{N} (B_{i,j} - C_{i,j})$	

Figure 2. Monte Carlo scatterplots 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, standardized measures of financial value). The data were recalculated from those presented by [18] using Matlab 2018R and a cellular automata approach.

3.2. Mid Stage

Figure 2B shows that moving on from the early stage topography, to a successful ambidextrous topology in the STP, is linked to a serious jump in productivity. Comparing the situation at 400 on the abscissa, the simple topology maximum yields around 20,000 MU, while the ambidextrous maximum is around 5,000,000 MU. As expected from the theory of Stiglitz, the unfortunate down-side is that if the transition is not managed well, then the losses are also very high, also around 6,000,000 MU. However, for STPs, the paradox is that to avoid unwanted 'lock-in' with firms using old technology, the STPs must constantly choose a risky influx of innovative firms that utilize new technology and ideas, so the decision about how STPs best choose incoming client firms is crucial, otherwise, at this stage, the STP could make sub-optimal decisions and fail rapidly, punishing the taxpayer and those firms who correctly chose to inhabit the STP [34]. Al-Kfairy et al. [18] inferred that the tipping point involving the inclusion of experienced decision-makers from two large firms is within 20 years, helping the CI to choose the best-fit incoming inhabitants. Involving more than two large firms did not improve decision-making significantly, but including more than two large firms contributes to exponentially rising transaction costs [18]. Transitioning from the initial star topology to an ambidextrous topology enhances knowledge spill-over through mechanisms such as networking between firms, and indeed various studies such as [41–43] have reported that networking within business clusters ('on-STP'/'on-cluster' firms) is highly significant in stimulating innovation to levels well above those found in the more isolated ('off-cluster') SMEs.

At this stage, off-cluster firms outnumber on-cluster firms. The innovation output of off-cluster firms is lightly related to R&D expenditure, but not to networking (social) expenditure [34]. A summary is given in Table 1:

Table 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 [34].

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 [37,40] and recalculated, and the results are presented in Table 2.

Table 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 Table 2 shows, the mature and well-established STP accounts for a large percentage of regional employment, although at this stage the growth in the number of on-STP employees is flat, presumably due to 'churn', i.e., equal numbers 'graduating' and leaving the STP, as new arrivals. The mid-stage STP employment situation, where decision-making is bolstered by two large firms on-cluster, is significant and rising, leading to over half a percent of regional employment being on-STP. The early-stage STP lacks support from large firms, and while its on-STP employment growth rate seems good, this may be due to the relatively small numbers involved, this STP being responsible for only 0.1% of regional employment [40].

3.3. Maturity

Clearly, it is arbitrary to say when an STP is 'mature', but taking some of the successes (e.g., Kista, WISTA, Research Triangle Park, Sophia Antipolis, Mjärdevi, Cambridge and Oxford STPs) into account, perhaps >30 years could be a reasonable figure. Such large mature STPs are the 'rock stars' [20] of the tech entrepreneurship ecosystem, although they can have their ups and downs (see [44]). They consist of a self-supporting churn of new tech entrepreneurs and serial entrepreneurs, well connected to each other and to venture capital [14]. Decision-making is well-supported due to many inhabitants being large firms. Universities find this stage the most attractive stage.

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' [45] scenario because at all stages, on-STP firms are, on average, more protected against external economic shocks [34,46] 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 [47] and substantially confirmed using GARCH models [48] and also by using wider economic indicators [46].

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., [49]). Indeed, Crescenzia et al. [50] indicated that geographical proximity is only weakly correlated with efficacy in external networks. Interestingly, more recent preliminary results presented by [19] imply that when firms leave the STP, they may not move far away. Kussainov et al. [19] measured firm density around several UK STPs and found that for IT-specializing STPs and firms, as well as biotech-specializing 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 [51]. 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., [52]) may well be reducing the reliance of off-cluster biotech firms on centralised large facilities. This concept is supported by results from open markets [53] which found that technological networks are more beneficial than physical close associations, and indeed the results presented by [54] reinforce this, showing off-cluster firms diffusing outward to a distance of up to ~8 km, a figure in good agreement with [19]. 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.

4. A New Model?

Despite criticisms of life cycle models generally, [9,55] produced a life cycle model for STPs. Figure 3 presents a similar model derived from the analysis of the data-driven results presented here.

As shown in Figure 3, micro-firms tend to leave the STP within 5 years or succeed in growing with the STP. The STP needs an influx of new innovation, and attracting two or more large firms within 20 years enables the CI to make better decisions. Without this, the STP may stagnate or devolve to a low-innovation park. Firms may depart the STP at a size of around 120 employees and some of these firms may re-settle in an annular ring 4–7 km away. When the STP is large and fully functional, successful tech entrepreneurs may become serial entrepreneurs or business angels, returning to found or otherwise help small firms in their early stages [56].

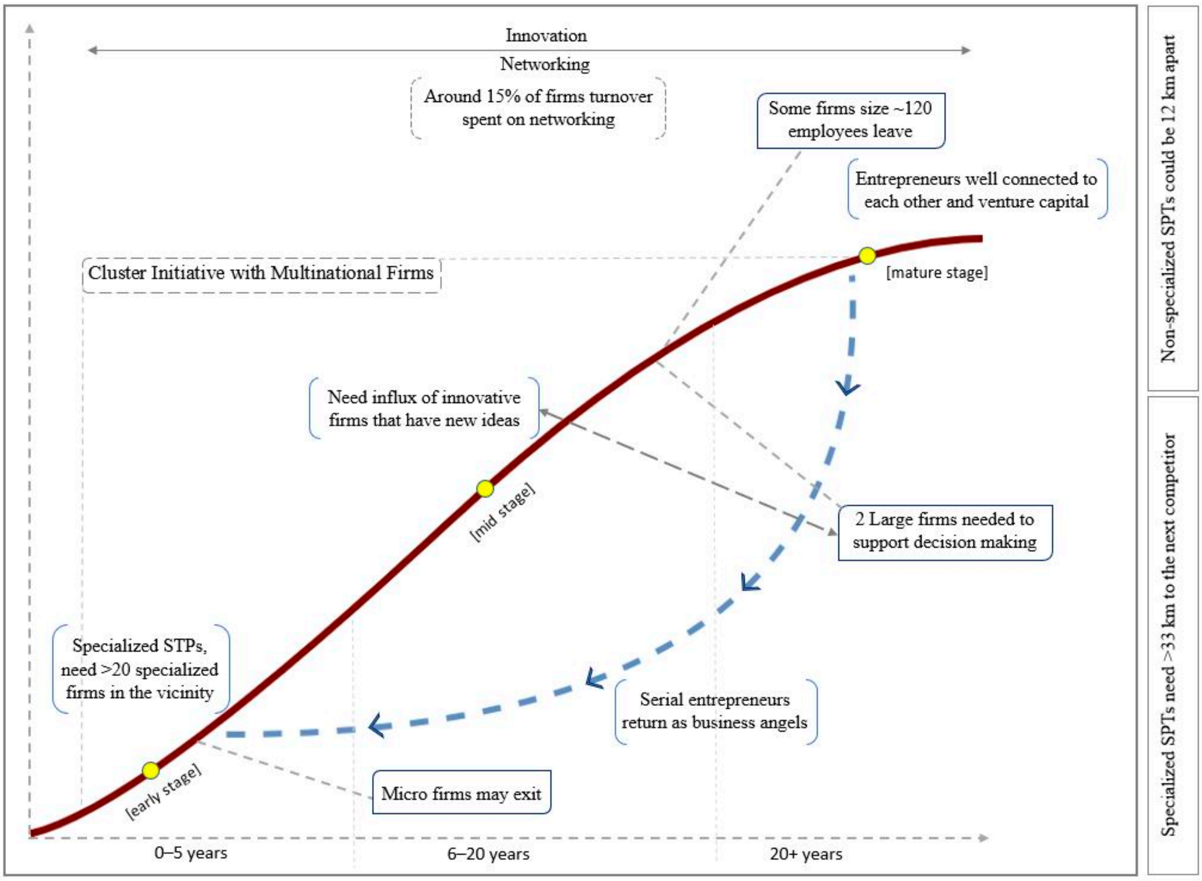


Figure 3. Graphical overview of the findings.

5. Future Directions

Several future scenarios for STPs have been formulated (see, e.g., [57]) 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 3 may still act as a guide.

Additionally notable are the indications that the triple helix model is evolving, and the recent effect of decentralizing 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.

6. Conclusions

Nobel laureate Paul Romer focussed attention on technological innovation, suggesting that market economies alone tend not to generate sufficient new ideas and that '*well-designed government actions*' [58] are needed to stimulate more innovation (e.g., subsidies for research and development, funding research at universities and establishing STPs). For example, it is generally unknown which measures work best in helping the national spend of a state to underpin that state's national industrial strategy. Indeed, there is a research gap regarding the links between stakeholders (including research councils) and the state, regional/local government, the STP organization itself (and STP associations), and the client firms which inhabit it, as well as how external ('off-cluster') firms and local associations (Chamber of

Commerce, etc.) contribute, because of the lack of clear data-driven indicators. The present authors strive to answer some of these points.

6.1. The Entrepreneurial University

Concerning universities and entrepreneurial motivation, Hegde and Tumlinson [59] built two mathematical models of probabilistic nature, mathematically reduced to a nonlinear Bayesian optimization problem, showing that employees transitioning to entrepreneurship have relatively higher ability than credentials. This represents a paradox for the traditional university spinouts where academics' credentials are good but entrepreneurial intent and experience are low. Further drivers and obstacles have been described by [60].

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 [11,12]—for a more general discussion, see Tidd et al. [61], p351–355. Certainly, there are optimistic academic (or student) start-ups grounded on the premises of many universities, but [20] shows that on average, on-campus locations are no better than others in attracting serious, specialized, 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 [62] could reveal more detail around these questions.

The work of Johnston and co-workers [30–32] 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?

6.2. Sustainablity

Sustainability depends on several factors—for example the interdependence of location and population density: Pugh et al. [6] reported on the failings of STPs that have too few (potential) client firms in the area. Very basic metrics such as the degree of inhabitancy (minimum how many firms in a viable STP?) and turnover/churn rates at the different developmental stages are largely unknown, although Mondal et al. [20] reported that for high-value specialized STPs, over 20 similarly specialized firms should be in the surrounding (~8 km) locale to support a minimum viable base for the pharmaceutical sector.

Good organizational behaviour is essential in STP management, especially regarding the transition from a simple "star" topology to a complex ambidextrous topology, or the STP will not progress and not grow. Established and still growing STPs may also have difficulty in exhibiting the required degree of ambidexterity to minimise the tension between collaboration versus opportunity [63], and conflict versus risk (e.g., [64]) in a park containing many different types of organization.

Mondal et al. [20] reported that in the UK, STPs can be as little as 12 km apart if the STPs are not competing, but measured an average of 33 km apart for competing STPs. Cluster spatial autocorrelation measures could deliver improved measurements of cluster strength among neighbouring STPs, but in practice, precise data can be difficult to obtain [65], and thus may need improving. One possibility could be including, e.g., the Kolmogorov theorem (see, e.g., [66]).

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, [23] found entrepreneurial knock-on effects from academia while [24] 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 organizational architecture determines corporate performance, and one factor not examined here involves micro-level practices at the organizational structure level of, e.g., technology transfer offices. Indeed, Brescia et al. [67] initiated studies on successful tech transfer departments.

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