The city as a local innovation system: How public institutions support the development of emerging technologies

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Cities have historically been the locus and driver of emerging technologies, but there is little understanding of how institutional structures at the city-level foster cutting-edge innovation. We introduce the Local Innovation System (LIS) as a distinct concept from National/Regional Innovation Systems, to highlight the unique opportunities and constraints that cities have to contend with. Three global cities - New York City, Singapore, and Beijing - are selected as case studies to investigate how public institutions drive the development of emerging technologies within their respective LIS. We find that the LIS is characterized by institutional structures that tolerate the technological risk profile, uncertain development trajectories and local implications of emerging technologies. From the experiences of these cities, we propose three general principles: (1) adopt mission-oriented innovation programmes, (2) grant greater autonomy to public institutions, and (3) take a long-range perspective on innovation in the city.

1. Introduction

1.1 Cities and Innovation

Why are cities disproportionately the innovation locus for emerging technologies?

Innovation is an important driver of economic growth and is recognised as a spatial process that is heavily dependent on local conditions.[1] The development of new products and processes leads to local competitive advantages for firms and for the market collectively. Innovative firms draw on local externalities for knowledge spillovers, institutional support, skilled labour, and critical supply chains. It has been empirically observed within the economic geography domain that the diversity and volume of economic activities happening in cities are important for attracting innovation.[2,3] Cities are the locus for innovation because of the tremendous positive externalities of agglomeration.

Specifically, emerging technologies - processes and products that are characterised by radical novelty and impact - have caught the attention of many innovative cities looking for the next frontier of their economic growth. Emerging technologies have the potential to cause 'creative destruction',[4] where previous ways of doing things become outmoded and the market reaches a new equilibrium. With the knowledge that emerging technologies could potentially cause radical changes in the existing production function, cities with first-mover advantages could quickly become the economic hub for new production systems.[5] These major technology shocks increase demand for skilled workers and

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[1] Camagni, R. & Capello, R. (2009). 'Knowledge-based economy and knowledge creation: The role of space', in U. Fratesi & L. Senn (eds) *Growth and Innovation of Competitive Regions: Advances in Spatial Science*. Berlin, Heidelberg: Springer.
[2] Henderson, V., Kuncoro, A. & Turner, M. (1995). 'Industrial development in cities', *Journal of Political Economy*, 103(5), pp. 1067-90.
[3] Glaeser, E. L., Kallal, H., Scheinkman, J. A. & Schleifer, A. (1992). 'Growth in cities', *Journal of Political Economy*, 100(6), pp. 1126-52.
[4] Schumpeter, J. (1942). *Capitalism, socialism and democracy.* New York: Harper.
[5] Cozzens, S., et al. (2010). 'Emerging technologies: Quantitative identification and measurement', *Technology Analysis & Strategic Management*, 22(3), pp. 361-76.

new investments,[6] therefore creating (potentially significant) economic dividends for cities which are home to the *disruptors*, as opposed to the *disrupted*. Historical examples include Silicon Valley's ascent when silicon-based transistors and integrated circuits set off a cycle of innovation in microcomputers, or when Henry Ford's innovative automobile manufacturing processes spurred Detroit to become an auto-industry powerhouse. Increasingly, cities are positioning themselves as the equivalent hubs for emerging technologies, whether in artificial intelligence, electric vehicle manufacturing, solar technologies, biotechnology etc.

Developing cities into innovation hubs is often an 'accidental' process that unfolds through a diverse assemblage of institutions, actors and policy proposals.[7] While the trajectories of *individual* innovation processes may be more accidental in their unpredictability, cities have a track record of building institutions and setting policies to influence their own innovation *potential* - whether exogenously (e.g., attracting foreign investments) or endogenously (e.g., developing internal R&D capabilities). Beijing, San Francisco and New York alone accounted for 44.1% of global venture capital (VC) investments in 2020[8]. These cities have been more successful at becoming hubs for emerging technology innovation, not by chance or good fortune. This paper aims to understand how cities have increased their own innovation potential and supported the development of emerging technologies by building the institutional capacity to do so.

1.2 Local Innovation Systems

Is there a disconnect between national and local innovation systems?

Innovation is embedded in a network of economic, political and social institutions, as well as varied stakeholders, including academics, entrepreneurs and regulators. At the national level, these collective elements are commonly known as the 'National Innovation System'[9] (NIS). This framework has helped the global innovation community identify benchmarks, challenges and opportunities for knowledge creation, regulatory environments, immigration policies, etc. For instance, the Defense Advanced Research Projects Agency (DARPA) in the United States has been hailed as an "ambitious innovation organization model" for pursuing mission-oriented, high-risk high-reward technical research programmes.[10] DARPA-style research agencies have been replicated or proposed in Germany (Federal Agency for Disruptive Innovation), Japan (Moonshot R&D) and the United Kingdom (Advanced Research and Invention Agency), among others.[11] Similarly, new regulatory regimes are being experimented in various NIS to promote emerging technologies in an equitable and ethical way. The European Union's General Data Protection Regime (GDPR) has enshrined new standards for data protection in the internet age, giving inspiration to similar legislation including in Singapore (Personal Data Protection Act), South Korea (Personal Information Protection Act).

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[6] Kemeny, T. & Storper, M. (2020). 'Superstar cities and left-behind places: disruptive innovation, labor demand, and interregional inequality', *London School of Economics and Political Science, LSE Library*.
[7] Coletta, C., Heaphy, L. & Kitchin, R. (2018). 'From the accidental to articulated smart city: The creation and work of 'Smart Dublin'', *European Urban and Regional Studies*, 26(4), pp. 349-64.
[8] https://startupsusa.org/global-startup-cities/
[9] Atkinson, R. D. (2020). 'Understanding the U.S. National Innovation System, 2020', *Information Technology & Innovation Foundation*.
[10] Bonvillian, W. B. (2018). 'DARPA and its ARPA-E and IARPA clones: a unique innovation organization model', *Industrial and Corporate Change*, 27(5), pp. 897-914.
[11] The Economist. (5 June, 2021). 'A growing number of governments hope to clone America's DARPA'. Retrieved from: https://economist.com/science-and-technology/.

Many of these NIS elements are applied at the national/federal level, often without contextualizing to regional/local characteristics. Although there are obvious economies of scale to national-level arrangements, they do not consider unique city level requirements and prevent local experimentation. Proponents for greater city level autonomy suggest that cities should have greater political power in designing their own analog of the NIS - a Local Innovation System (LIS). Although the NIS framework has been extensively studied, the LIS has not been well characterized largely because of the sheer diversity of innovation cultures and ecosystems among cities. Moreover, each LIS is inextricably tied to their respective NIS and their relational status to other cities in the global innovation circuit. The elements of the LIS are constrained by their positionality within regional supply chains, international talent networks, and global regulatory regimes.

Cities such as Beijing and Singapore which are associated with state entrepreneurialism (where central planning and market capitalism converge) take a bureaucratic top-down approach to direct innovation activities. Cities with stronger academic traditions, including Boston, Massachusetts and Oxford, England, might emphasize university spin-offs and R&D-based ventures more prominently. Other cities may even structure their LIS around the peculiarities of specific industries, such as how innovation in Basel, Switzerland is anchored by pharmaceutical and biotech value chains, or how Hsinchu, Taiwan has become the world's most vital hub for semiconductor innovation. Notwithstanding the track record of innovation in these global innovation hubs, a large number of cities are attempting to "jump on the innovation bandwagon" with neither ambition nor achievement.[12]

Here, there is a tendency for city governments to conflate technological innovation with *civic* innovation. The former focuses on high-risk high-reward technical innovation and has the potential to drive significant economic growth; the latter seeks to solve municipal problems using new organizational approaches, products, and processes. While civic innovation may sometimes be technological, they are often not disruptive in nature (or are they intended to be), and do not leverage emerging technologies. Similarly, while technological innovation often has national or global ambitions, it may have meaningful direct applications in the civic or public realm. Although this paper is most interested in studying how LIS accelerates technological innovation, it will also discuss how the LIS navigates the overlapping domains of emerging technologies and civic innovation.

However difficult, understanding the structure and dynamics of LIS is important to assess the quality of city level innovation policies and institutions. Upstream, policymakers can identify city level opportunities to make R&D investments; downstream, such a framework can help evaluate and course-correct a city's innovation strategy. Yet there have been few attempts to systematically analyze the contours of LIS and how they support the development of emerging technologies. Although the NIS framework has been helpful for thinking about macro-business environments, trade and tax policies, as well as federal-level support, the idiosyncratic dynamics at the city level are equally important. In the context of emerging technologies, it is particularly important to understand how city level innovation policies and institutions are influencing knowledge creation. Prior research has observed that the overall quantity, quality and complexity of knowledge in a city triggers innovation due to an increased scope for recombinant generation of new knowledge needed for emerging technologies.[13] How cities develop institutions and policies to encourage knowledge creation is therefore an important element of any LIS.

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[12] Burstein, R. (25 June, 2013). 'Most cities don't need innovation offices'. Retrieved from: https://slate.com/technology.

[13] Antonelli, C., Crespi, F. & Quataro, F. (2020). 'Knowledge complexity and the mechanisms of knowledge generation and exploitation: the European evidence', *Research Policy*.

Hence, this paper identifies common principles for promoting emerging technologies at the city level through a careful analysis of the LIS in three global cities. These principles act as a reference point for academics to develop a framework for analyzing city-level innovation systems and for policymakers to evaluate their own LIS.

2. Methodology

This paper will analyze the premise, organizational structure and modus operandi of public institutions promoting emerging technology innovation in three global cities (**Table 1**). These global cities - New York City (NYC), Singapore, and Beijing - have been selected based on their prominence in the global innovation landscape, and more importantly, that they provide analytical richness in their socio-political and institutional diversity. NYC exhibits strong free market dynamics, in contrast to Singapore and Beijing's central planning tradition. NYC and Beijing are part of larger hinterlands; not only are they key global innovation powerhouses, they are also strategic nodes in their respective NIS. Singapore - as a city-state - is an important exception where the lines between national and local innovation systems are blurred, potentially offering insights into how the NIS framework can be implemented at the city level. These cities also vary significantly in terms of their immigration, trade and tax policies. Ideological, geopolitical differences, and their relations with political blocs (e.g., the European Union, China's Belt-Road Initiative) also influence city level innovation policies.

At times, the city level institutions cannot be neatly separated from their respective NIS, either because they were born out of NIS policies (e.g., Beijing Academy of Artificial Intelligence) or that the country does not distinguish between national and local innovation systems (e.g., Singapore). The comparative analysis does not attempt to exhaustively catalogue each city's innovation systems, but evaluates specific public institutions to understand how they have shaped or been shaped by their LIS. Through an institutional analysis, we glean insights into each city's LIS characteristics.

Table 1: List of public institutions selected for analysis

	City	**Country**	**Institution**
1	New York City	United States	Mayor's Office of the Chief Technology Officer
2			NYC Economic Development Corporation
3	Singapore	Singapore	SGInnovate
4			Agency for Science, Technology and Research
5	Beijing	China	Zhongguancun Science Park
6			Beijing Academy of Artificial Intelligence

3. Comparative analysis of local innovation systems

3.1 New York City, United States

New York City is home to more than 9,000 startups and nearly 300,000 employees in technology-related roles[14]. With technology conglomerates such as Google, Amazon, and Facebook rapidly expanding their office footprint in the City (in spite of the COVID-19 pandemic) and funneling more investments into technology R&D. Areas such as Chelsea, Manhattan and the Brooklyn Navy Yard have become de facto innovation hubs. Brooklyn, in particular, is fast emerging as a "national leader" in the innovation economy, witnessing a 356% startup growth rate in the past decade[15].

Crucially, NYC's focus on technology innovation was sharpened after the 2008 financial crisis. The rate of employment growth in the technology startup sector has been increasing by 18% year-on-year since[16], eclipsing the overall 12% employment growth in NYC. It is widely acknowledged that NYC's tech startups have developed around the City's dominant industries, such as finance, advertising, media, fashion, and health. However, the lack of affordable office rentals, scarce tech talent, and insufficient seed capital for startups limited the growth of innovation-related activities. NYC's LIS evolved against this backdrop of opportunities and challenges.

3.1.1 Mayor's Office of the Chief Technology Officer

The NYC Mayor's Office of the Chief Technology Officer (MOCTO) sets out to ensure that technology is "inclusive, accessible, human-centered, and works for all New Yorkers".[17] It also envisions a utilitarian vision of technology as a 'tool' to achieve "fairness" while also making the city "future-ready". From the outset, the MOCTO's values-centric approach to innovation differs from the knowledge- or profit-driven agenda common in NIS. By focusing on issues of equity and ethics, the MOCTO aligns itself with the growing technology ethics community in the US and Europe. This values-centric approach is also reasonable given that the MOCTO is politically motivated to ensure that any technology project is well-received by NYC residents while ideologically aligned to the increasingly progressive technopolitics in the western world. However, it is not obvious why the application of new technologies to pursue fairness is the best way to achieve equity in society.

Branding aside, the MOCTO has made key contributions to the LIS: (1) setting a mission-oriented innovation agenda through NYC[x] Moonshots, (2) assembling private, public and academic institutions to address market failures in public innovation, and (3) facilitating innovation projects at the neighborhood-level. The first two initiatives will be elaborated in detail as they deal with emerging technologies; neighborhood projects such as the NYC[x] Co-Lab: Brownsville[18] call for participatory planning of tech-lite solutions that do not advance emerging technology innovation.

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[14] Zukin, S. (2020). 'How New York City became a technology hub', *Oxford University Press's Academic Insights for the Thinking World*. Retrieved from https://blog.oup.com.
[15] Dvorkin, E. & Eisenpress, C. (2020). *Growing and diversifying Brooklyn's Innovation Economy*. New York City: Center for an Urban Future.
[16] Mulas, V. & Gastelu-Iturri, M. (2016). *New York City: Transforming a city into a tech innovation leader*. The World Bank.
[17] https://www1.nyc.gov/assets/cto/
[18] https://www1.nyc.gov/assets/cto/#/project/brownsville-co-lab

NYC[x] Moonshots

The objectives of NYC[x] Moonshot Challenges are tied to the OneNYC Plan, a city-wide strategy manifesto covering nine volumes - from building a vibrant democracy to investing in modern infrastructure.[19] For instance, MOCTO launched the Connectivity Challenge in 2017 to deliver free 5G-enabled wireless internet service on Governor's Island.[20] Governor's Island had a disrepute for being poor cellular connection, thus diminishing visitor experience and leading to inequality in data access for its residents. The Challenge therefore addressed longstanding infrastructure problems while setting up the Island to become a "living laboratory" for climate research[21] by providing high-speed data transmission from remote sensing networks. At the outset, the Challenge provided entrepreneurs and technology startups with a clearly defined problem (i.e., poor connectivity), without assuming what the 'correct' solution should be. This mission-oriented challenge also facilitated real-world testing on Governor's Island with seed capital of $25,000 for finalists. Fiberless Networks won the Challenge and installed free, high-speed public Wi-Fi infrastructure around the Island.

Subsequently, several more Challenges have been launched in cybersecurity, electric vehicle adoption, and financial inclusion. A Moonshot Challenge playbook was also published by MOCTO to help other municipal governments launch their own challenges. The success of these mission-oriented challenges is tied to: (1) a well-defined problem that has been validated through stakeholder workshops, (2) a risk-taking willingness to invest in the testing of unproven solutions in real-world environments, and (3) openness to course correction (or pivoting) in the Challenge's scope and requirements.[22]

Addressing market failures in public innovation

Market failure in civic technology innovation - or more broadly public innovation - can be traced to large positive externalities (enjoyed by the general public) where firms may have limited appropriability (i.e., firms have limited ability to retain the value it creates).[23] While affordable public housing or protected bicycle lanes may be obvious public goods, there are few private incentives to attract firms' investment. Moreover, the business-to-government (B2G) procurement cycle is lengthy and complicated by bureaucratic rules, setting up higher barriers to entry relative to business-to-business (B2B) market entry strategies for innovative firms. These market failures diminish public innovation below socially optimal levels.

MOCTO addresses critical market failures by assembling city agencies and academic partners to develop innovation solutions. This includes the open-source Easy Localization System Access (ELSA) that automatically and continuously updates digital content in 11 different languages commonly spoken in NYC using neural machine translation techniques.[24] Real-time public safety information and other critical digital content can be automatically delivered to vulnerable

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[19] https://onenyc.cityofnewyork.us/
[20] https://www1.nyc.gov/html/nycx/govchallenge.html
[21] Poon, L. (28 June, 2021). 'How NYC Plans to Create a 'Living Laboratory' for Climate Research'. Retrieved from Bloomberg: https://www.bloomberg.com/.
[22] NYC Mayor's Office of the Chief Technology Officer. (22 October, 2018). 'Let's go to the moon'. Retrieved from Medium: https://medium.com/nyc-mayors-office-of-the-cto/.
[23] Martin, S. & Scott, J. T. (2000). 'The nature of innovation market failure and the design of public support for private innovation', *Research Policy*, 29(4-5), pp. 437-47.
[24] https://elsa.cityofnewyork.us/

communities in multiple languages. MOCTO convened the US Digital Response and the NYC Mayor's Office of Immigrant Affairs to commission this project during the pandemic.

MOCTO also taps into deep research talent in academic institutions to launch cutting-edge projects. The City Scanner Pilot tested low-cost mobile air quality and environmental sensors on city vehicles together with the MIT Sensable City Lab and the Department of Health and Mental Hygeine, among other government agencies.[25] Similarly, MOCTO assembled a consortium of partners in the NYC Mayor's Office of Climate Resiliency, New York University and the City University of New York to deploy FloodNet: an online dashboard to share real-time data on flood-prone areas.[26]

3.1.2 NYC Economic Development Corporation

The NYC Economic Development Corporation (NYCEDC) is a not-for-profit corporation that is responsible for driving economic development and encouraging "shared prosperity" across NYC's five boroughs by "strengthening neighborhoods and growing good jobs".[27] Its wide mandate ranges from supporting industry growth to facilitating private sector investments, giving the NYCEDC strong fiscal, planning and agenda-setting powers to develop emerging technologies in NYC. Unlike MOCTO, the NYCEDC is not involved in developing emerging technologies, nor is it mission-oriented. Instead, the NYCEDC supports the development of physical infrastructure and institutions to support broad areas of emerging technologies such as blockchain, cybersecurity, urban technologies, and climate technologies among others.[28]

The NYCEDC's ability to set up new institutions from scratch raises a meta-question: how do we design institutions that specialize in building institutions? Since emerging technologies likely require a very different set of institutions and regulatory structures,[29] it is reasonable to ask how we can continuously and efficiently build new institutions that are fit-for-purpose. Remarkably, the NYCEDC has been able to 'learn' the evolving requirements of innovation[30] and responds to national and global innovation trends by building new institutions. These institutions may range from knowledge-generating (e.g., research labs), to funding and accelerating new ideas (e.g., venture accelerators), to ecosystem anchors which aggregate networks of innovators, funders and industry leaders.

LifeSci NYC + Applied Life Sciences Hub

The LifeSci NYC is one such example of NYCEDC's 'institution-building' effort. This is a 10-year, $1 billion investment to establish NYC as a biopharmaceutical powerhouse. The centerpiece of this investment is a $100 million Applied Life Sciences Hub which NYCEDC President and CEO James Patchett calls the "Bell Labs for biotechnology", where new discoveries, cures and businesses will be spun out.[31] Yet, the original Bell Labs was a corporate research laboratory co-owned by Western

[25] http://senseable.mit.edu/cityscanner/
[26] https://www.floodnet.nyc/
[27] Patchett, J. (2019). *New York City Economic Development Corporation.* Retrieved from: https://edc.nyc/sites/default/files/2019-10/NYCEDC-Operations-Accomplishments-FY19.pdf
[28] https://edc.nyc/program/
[29] Nelson, R. R. & Nelson, K. (2002). 'Technology, institutions, and innovation systems', *Research Policy*, 31(2), pp. 265-72.
[30] Harper, D. A. (2018). 'Innovation and institutions from the bottom up: an introduction', *Journal of Institutional Economics*, 14(6), pp. 975-1001.
[31] https://lifesci.nyc/news/new-york-city-seeks-proposals-100m-life-sci-hub

Electric and AT&T - a fundamentally different institutional structure compared to the large-scale 'business park' concept that the Applied Life Sciences Hub would take on. The Hub, as an institution formalized by the NYCEDC, is an assemblage of real estate, tax systems, talented researchers, academic collaborations, and investments.

The Hub aims to bring together innovative biopharmaceutical companies, research labs and startups through preferential industrial policy (e.g., tax subsidies, physical infrastructure) to create positive economic externalities. Like many other domestic and international attempts,[32] this is an artificial attempt to emulate the organic success of Silicon Valley and Route 128 in spurring emerging technology innovation by clustering high-technology firms in the same location. Theoretically, industry concentration could generate local knowledge spillovers, create a thick labour market that benefits knowledge creation, and facilitate tight backward and forward linkages in the supply chain.[33,34] Whether this materially results in stronger innovative performance is contentious.[35,36] Some suggest that clusters are innovative because they attract innovative firms,[37] thus downplaying the benefits of industry clustering.

However, a technology cluster itself is not an institution. This is where LifeSci NYC differentiates the Applied Life Sciences Hub from conventional high-tech concentrations found elsewhere. A robust understanding of the biotech industry is necessary to develop relevant institutional support for cluster development. For instance, the locational advantages that benefit biotech companies include access to risk capital, technical and regulatory talent, and a 'whole-chain-culture' where the entire process of pharmaceutical development can be carried out within the region.[38] These locational advantages have been shown to develop somewhat organically (e.g., in Basel, Switzerland[39]), but it is unclear how or if they can be replicated intentionally. As an institution that shapes business norms, LifeSci NYC attempts to replicate the conditions for these locational advantages by:

1. Reducing networking costs within the cluster.

   The Hub is conceived to be a "large-scale R&D organization" committed to leading R&D operations. This is not merely a collection of pharmaceutical companies and research labs, but an organized orchestration of researchers, corporates, and investors where networks are intentionally constructed. In the context of the biotech industry, proximate networks between biopharma companies, contract research organizations, and industry regulators are important

[32] Bas, T. G. & Zhao, J. (2012). *Comparing High Technology Firms in Developed and Developing Countries: Cluster Growth Initiatives*. Hershey, PA: IGI Global.
[33] Glaeser, et al. *Growth in cities*.
[34] Krugman, P. (1993). 'On the number and location of cities', *European Economic Review*, 37(2-3), pp. 293-8.
[35] Chan, K. A., Oerelamans, L. & Pretorius, M. W. (2010). 'Knowledge exchange behaviors of science park firms: The innovation hub case', *Technology Analysis & Strategic Management*, 22(2), pp. 207-28.
[36] Beaudry, C. & Breschi, S. (2003). 'Are firms in clusters really more innovative?', *Economics of Innovation and New Technology*, 12(4), pp. 325-42.
[37] Ferras-Hernandez, X. & Nylund, P. A. (2018). 'Clusters as Innovation Engines: The Accelerating Strengths of Proximity', *European Management Review*, 16(1), pp. 37-53.
[38] Dörhöfer, S. & Minnig, C. (2012). 'Clusters as geographically bounded organizational fields: The meaning of proximity in the Basel pharmaceutical industry', *American Journal of Business and Management*, 1(4), pp. 259-70.
[39] Gugler, P., Keller, M. & Tinguely, X. (2015). 'The role of clusters in the global innovation strategy of MNEs: Theoretical foundations and evidence from the Basel pharmaceutical cluster', *Competitiveness Review*, 25(3), pp. 324-40.

for accelerating drug testing and clinical trials. Formal and informal relationships among managers can improve understanding of regulatory requirements and clinical best practices.

2. Absorbing technology risks through physical and financial investments.

   Successfully developing a drug is notoriously expensive and time-intensive, with a single drug costing upwards of $2.5 billion over 10-15 years.[40] The difficulty of developing breakthrough drugs is a deterrent for aspiring biotech entrepreneurs and investors alike. LifeSci NYC's focus on early-stage biotech seed funding could potentially increase the pipeline of promising drug candidates. Through its funding partnership with VCs[41] and collaboration with life sciences accelerator SOSV IndieBio,[42] the NYCEDC absorbs some of the venture risk in developing emerging biotechnologies. This augments the implicit risk-reward ratio for both entrepreneurs and investors, while increasing the pipeline of drug candidate acquisitions for larger pharmaceutical companies. Moreover, the Hub provides 'ready-to-occupy customizable wet lab' and prototyping studios for life sciences companies,[43] thereby reducing R&D costs.

3. Augmenting the life sciences talent pipeline.

   LifeSci NYC takes a long view of local talent development by setting up programmes to make the life sciences an attractive career path for high school, undergraduate, and graduate students. The New York Bioforce, for instance, offers underserved NYC high school students 140 hours of "strategically developed training" to prepare them for mutually beneficial placements at biomedical research labs and companies.[44] The LifeSci NYC Internship Program funds high calibre undergraduate and graduate students to work at host companies.[45]

It is premature to evaluate whether these institutional efforts will be successful in growing NYC's life sciences industry. However, it is worth studying (1) whether NYCEDC's attempt at building an institution around high-tech cluster development could be more effective than other industry clustering policy, and (2) whether this can be repeated across industries and geographies.

3.2 Singapore

Singapore is a city-state with 5.7 million population and the fourth highest GDP per capita in the world. With a land area smaller than NYC, the Singapore government positions itself as the 'launchpad' to the greater Southeast Asian market which boasts a 630 million population and a 5.5% annual growth rate.[46] Singapore is the regional headquarters to 59% of technology multinational companies (MNC)[47] and more than 4,300 technology startups.[48] The government sees its future prosperity tightly linked to its ability to develop a "knowledge-based innovation-driven economy and

[40] Calza, F., Feretti, M., Panetti, E. & Parmentola, A. (2020). 'Moving drug discoveries beyond the valley of death: The role of innovation ecosystems', *European Journal of Innovation Management*.
[41] https://edc.nyc/program/nyc-early-stage-life-sciences-funding-initiative
[42] https://indiebio.co/
[43] https://cure.345pas.com/ecosystem/
[44] https://www.hypothekids.org/new-york-bioforce/
[45] https://lifesci.nyc/lifesci-nyc-internship-program
[46] https://www.usasean.org/why-asean/growth
[47] EDB Singapore. (2019). *Singapore's Tech Ecosystem*. Singapore: Economic Development Board.
[48] https://www.enterprisesg.gov.sg/blog/startups/6-global-startups-that-want-to-move-to-singapore

society".[49] In its most updated Research, Innovation and Enterprise 2025 Plan (RIE 2025), the Prime Minister's Office outlined four strategic domains where it will accelerate the development of emerging technologies: (1) Manufacturing, trade and connectivity, (2) human health and potential, (3) urban solutions and sustainability, and (4) Smart Nation and digital economy.[50] Although Singapore has invested heavily in innovation, the ecosystem is challenged by the risk of over-dependency on government involvement and a limited local technical/entrepreneurial talent pool.[51]

In contrast to other global cities, Singapore's local innovation system is also a national level system. It demonstrates the potential for a LIS to develop long-term planning capabilities and global linkages, given sufficient political and economic autonomy. The Singapore case study highlights how emerging technologies can be developed by joining up national-scale resources with local innovation processes, such as growing local talent pipelines and providing local businesses with cutting edge technologies developed by research institutes.

3.2.1 SGInnovate

SGInnovate is a private organization that is wholly owned and established in 2016 by the National Research Foundation of the Singapore government.[52] It describes its mission as to "launch, prove and scale deep tech products" by helping entrepreneurial scientists build deep tech startups.[53] As a thematic VC, it invests purely in the 'deep tech' category of startups that commercialize breakthrough scientific ideas, including artificial intelligence, quantum computing, and biotechnology. Since 2016, SGInnovate has invested S$50 million in more than 80 technology startups.[54] The explicit objective of commercializing technology-intensive products that emerge from local scientific research is interesting because of its market signaling effect. Firstly, it assumes that 'winning' emerging technologies can be presciently selected from lab to market. Secondly, that emerging technologies can be reliably 'launched, proven and scaled' in spite of the inherent uncertainties. Finally, it signals to VCs and other financial institutions that emerging technologies have high private returns on investment.

SGInnovate's investment thesis focuses on 'deep technology' startups that are characterized by high technology risk and novel scientific discoveries that can generate defensible intellectual property (IP).[55] Since many of these startups are built on scientific ideas that may be commercially unproven, an investor like SGInnovate has to contend with a longer runway to market and revenue.

[49] National Research Foundation. (2020). *Research Innovation and Enterprise 2020 Plan: Winning the Future through Science and Technology*. Singapore: Prime Minister's Office.
[50] National Research Foundation. (2020). *Research Innovation and Enterprise 2025 Plan*. Singapore: Prime Minister's Office.
[51] Eliasz, T., Wyne, J. & Lenoble, S. (2021). *The Evolution and State of Singapore's Start-up Ecosystem: Lessons for Emerging Market Economies*. Singapore: World Bank Group.
[52] Hoe, S. L. (2018). 'Building a smart nation: Singapore's digital journey', *Science and Technology Trends*, 9, pp. 86-95.
[53] https://www.sginnovate.com/deep-tech-nexus
[54] https://www.sginnovate.com/portfolio
[55] Asian Scientist. (2019). *Deep Tech Daredevils: The Rise of Entrepreneurial Scientists in Singapore*. Singapore: SGInnovate.

Increasing deep tech talent availability

To de-risk its portfolio of deep technology startups, SGInnovate has developed talent programmes to build 'deep tech talent'. It appreciates that the lack of deep technical talent is one of the limiting factors to commercial exploitation of breakthrough scientific ideas. Given the long runway to develop graduate/doctoral-level scientists and researchers in extremely niche fields, it has designed talent programmes that serve as shorter on-ramps into its portfolio companies. For instance, SGInnovate's Power^X traineeship programmes are intensive 9 to 12-month mid-career conversion schemes that equip working professionals with "essential competencies" to become entry-level robotics software engineers, full-stack developers, and cybersecurity specialists.[56] During the programme, trainees receive S$4,000 monthly stipends and subsidized modular training. The structured programming is complemented by on-the-job training with a relevant portfolio company. Not only does this subsidize the cost of deep tech talent for portfolio companies, but increases the total availability of technical talent in Singapore.

Another example is the Summation Programme[57] which allows portfolio companies to gain access to top talent from globally reputable universities. SGInnovate provides co-funding of up to 70%, thereby subsidizing the cost of talent. The import of deep tech expertise facilitates the exchange of knowledge and builds long-lasting knowledge transfers. In the field of emerging technologies, the recombination of ideas from different research labs is an important competitive advantage.

3.2.2 Agency for Science, Technology and Research

The Agency for Science, Technology and Research (A*STAR) works on "mission-oriented research" that advances scientific discovery and technological innovation.[58] The agency is a sprawling research organization of 6 national level initiatives, 10 biomedical research institutes, 6 science & engineering research institutes, 3 joint research institutions, an enterprise division to manage industry partnerships, a venture accelerator, numerous corporate divisions, and 6 newly launched horizontal technology programme offices (HTPO).[59]

As Singapore's lead public sector R&D agency, it serves as the bridge between the scientific research happening in academia and the commercial opportunities in industry. Like SGInnovate, there is a strong focus on exploiting scientific findings and technological innovations for commercial value, as demonstrated by its industry-focused mission statements (**Figure 1**).[60] Its "economic-oriented research"[61] is seen as a means for advancing industry and job creation. Implicitly, this has provided the necessary economic justification for high-risk R&D funding of unproven emerging technologies with industrial applications. It has also extended A*STAR's mandate to find commercial use cases for these technologies, whether through commercial spin-offs, technology transfers, or IP licensing. Since Singapore's relatively young R&D scene has neither an existing stock of research talent, nor does it have any significant homegrown industries, A*STAR effectively bootstraps new industries by becoming a "surrogate for a mature ecosystem".[62]

[56] https://www.sginnovate.com/power-x-robotics
[57] https://www.sginnovate.com/apprenticeship/organisations
[58] https://www.a-star.edu.sg/
[59] https://www.a-star.edu.sg/About-A-STAR/corporate-profile/organisation-structure
[60] https://www.a-star.edu.sg/About-A-STAR
[61] https://www.a-star.edu.sg/Research/overview
[62] Chok, L. (2020). 'Examining Singapore's biotechnology cluster development strategy', *London School of Economics & Political Science*. Unpublished.

1. Integrating our capabilities to create impact with multi-national corporations and globally competitive companies; 2. Partnering local enterprises for productivity and gearing them for growth; 3. Nurturing R&D-driven startups by seeding for surprises and shaping for success.

Figure 1: A*STAR's mission statements for developing industry sectors

Innovative Collaboration Models

A*STAR's collaboration models[63] help formalize knowledge transfer mechanisms between academia and industry. These collaboration models, or elsewhere known as research consortia, are "multi-party strategic alliances" where members have a vested interest in delivering research outcomes and thus respectively contribute valuable inputs to the research process.[64] The formation of academia-industry research consortia is most commonly seen in high velocity industries where technological innovation is required to break away from strong competitive rivalry (e.g., biotechnology, semiconductors, cloud computing). A*STAR's collaboration models prioritize flexibility in the number and type of stakeholders which conceivably produces different knowledge transfer outcomes (**Table 2**).

Table 2: A*STAR innovation collaboration models

Collaboration Model	**Description**	**Knowledge Transfer Outcomes**
Many to One	Several A*STAR research institutes may jointly collaborate with one industry partner. For example, SembCorp Marine (a global marine and offshore engineering group) is collaborating with 8 A*STAR research institutes to pursue innovation in Digital Design and Advanced Manufacturing.	Industry knowledge is shared with academics to facilitate understanding of how emerging technologies may be applied to real-world problems. Research institutes share best practices and technological know-how to create conditions for recombinatorial innovation.
One to One	A single A*STAR research institute collaborates with a single industry partner to either embark on a focused research project or to form joint research labs for a pipeline of projects. For example, Applied Materials (a materials engineering company) set up the Centre of Excellence in Advanced Packaging together with A*STAR's Institute of Microelectronics.	Similar to a Many to One model, a One to One model allows for long-term R&D efforts to solve challenging problems using relevant emerging technologies.
One to Many	A single A*STAR research institute collaborates with multiple companies to leverage the institute's core R&D capabilities for solving problems in pre-competitive sectors. For example, the Advanced Remanufacturing and	The research institute benefits from gaining an industry-wide perspective on how emerging technologies can augment pre-competitive sectors. The institute enjoys the ability to pilot emerging technologies across diverse industrial

[63] https://www.a-star.edu.sg/enterprise/connect/collaboration-models
[64] Eisner, A. B., Rahman, N. & Korn, H. J. (2009). 'Formation conditions, innovation and learning in R&D consortia', *Management Decision*, 47(6), pp. 851-71.

	Technology Centre is a consortium of over 80 members that include small and large enterprises alike.	settings, thus increasing their rate of learning and technical iterations. Significant risk sharing is enjoyed by the industry as they benefit from the externalities of more fundamental research breakthroughs by jointly participating in the testing and validation of new technologies.
Many to Many	Several A*STAR research institutes work with multiple companies to collaborate on thematic research areas. For example, the Pharma Innovation Programme Singapore (PIPS) is an industry-led platform that brings together A*STAR research institutes, biotech startups and global pharmaceutical companies to transform biopharma manufacturing processes.	This whole of industry approach to generating and testing emerging technologies brings together the full force of R&D capabilities to foster a city-level competitive advantage.

Although government involvement in facilitating the formation of research consortiums is not new, we typically observe that different government agencies play different facilitative roles - as the funder, principal investigator, and venture builder. In the UK, for instance, the national grant funding agency InnovateUK is a distinct institution from its many national research laboratories. A*STAR is unique in its flexibility to play different catalyst roles in the formation of research consortiums, providing it strategic advantage to develop emerging technologies with a host of industry and academic partners. In Eisner et al.'s theoretical motivation-process matrix of consortium formation,[65] research consortiums are thought to be either emergent or engineered depending on whether there is a dominant member organizing the consortiums. However, A*STAR's modus operandi suggests that research consortia can be 'engineered' without the public R&D agency being the 'dominant player'. Instead, the consortiums are often formed by open innovation calls and facilitated networks between A*STAR and other government agencies (e.g., Enterprise Singapore) in pursuit of national research priorities outlined in the RIE 2025. This is an important distinction as it demonstrates how public R&D agencies can engineer functional research consortiums that are aligned to the city's innovation agenda, while ensuring equitable appropriation of research outcomes.

Horizontal Technology Programme Offices

A*STAR's Horizontal Technology Programme Offices (HTPO) were recently introduced to coordinate research efforts across national R&D priorities in Singapore. HTPOs were established to "promote opportunities, assemble teams and curate projects and programs" that traverse across A*STAR's research institutes in five research areas: (1) agritech and aquaculture, (2) artificial intelligence, analytics and informatics, (3) health and medical technologies, (4) infectious diseases, and (5) urban and green technology.[66] In this way, the HTPOs are similar in tradition to horizontal technology policies whose objective is to promote technological development irrespective of industry sector or technology.[67]

[65] Ibid., 858.
[66] https://www.a-star.edu.sg/htpo
[67] Teubal, M. (1997). 'A catalytic and evolutionary approach to horizontal technology policies (HTPs)', *Research Policy*, 25(8), pp. 1161-88.

These thematic research areas were selected based on three considerations.[68] Firstly, these research areas build on Singapore's core R&D capabilities. This is congruent with studies finding that Marshallian externalities are stronger within clusters of closely related technologies.[69,70] For instance, the Infectious Diseases HTPO builds on pre-existing biopharma R&D capabilities (e.g., A*STAR Experimental Drug Development Centre, Bioniformatics Institute) and national epidemic response programmes (e.g., PREPARE[71]). Secondly, these research areas aim to generate a "multiplier effect" through the recombination of different knowledge bases. The hypothesis is that horizontal linkages of technology branches can further the R&D flywheel where there are synergies to be exploited. Nevertheless, the mechanisms behind recombination innovation need to be scrutinised; studies have found that technological proximity of knowledge bases may have negative effects on innovation outcomes, while organizational proximity has no outstanding positive effect.[72,73] Finally, these research areas are developed to address national and societal needs. While this may seem obvious, this utilitarian vision of HTPOs sets it aside from pure scientific research. Yet this static categorization of thematic research areas may be assuming that national and societal needs are fixed rather than in flux. It remains to be seen how responsive A*STAR's HTPOs are to the fast-changing nature of problems. There is also apparent inconsistency in the grouping of research activities: 'Artificial Intelligence, Analytics and Informatics' seem to describe a set of emerging computing technologies, 'Infectious Diseases' refer to a specific problem, and 'Urban and Green Technology' is an amorphous collection of technologies and problem areas that share the same urbanism/sustainability domain. Without greater clarity, this may lead to 'research creep' problems where the HTPO loses focus and prevent the HTPOs from being adaptable to new problem areas and emerging technologies.

An interesting feature of A*STAR's HTPOs is its explicit mission-oriented agenda. Each HTPO lays out R&D roadmaps answering long-range questions. For example, how might Singapore locally produce 30% of its nutritional needs by 2030? This functional (as opposed to sectorial) R&D agenda ensures that emerging technologies are applied to socially desirable ends.

3.3 Beijing, China

Beijing is one of the world's top technology hubs, with some suggesting that it has already outpaced Silicon Valley.[74] It is one of China's most important innovation poles and has been consistently among the top three Chinese cities with the largest volume of R&D investments and patent applications.[75]

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[68] A*STAR (10 March, 2021). 'Building strong systems on deep pillars', *A*STAR Research*. Retrieved: https://research.a-star.edu.sg/articles/features/building-strong-systems-on-deep-pillars/
[69] Klepper, S. (2010). 'The origin and growth of industry clusters: The making of Silicon Valley and Detroit', *Journal of Urban Economics*, 67(1), pp. 15-32.
[70] Neffke, F., Henning, M. & Boschma, R. (2011). 'How do regions diversify over time? Industry relatedness and the development of new growth paths in regions', *Economic Geography*, 87(3), pp. 237-65.
[71] https://www.nrf.gov.sg/rie2025-plan/human-health-and-potential
[72] Joris, K. & Oerlemans, L. (2006). 'Proximity and inter-organizational collaboration: A literature review', *International Journal of Management Reviews*, 8(2), pp. 71-89.
[73] Nan, D., Liu, F. & Ma, R. (2017). 'Effect of proximity on recombination innovation in R&D collaboration: An empirical analysis', *Technology Analysis & Strategic Management*, 30(8), pp. 921-34.
[74] Hynes, C. (2 November, 2017). 'Beijing -- Not Silicon Valley - Is The World's Top Tech Hub, Report Says', *Forbes*. Retrieved: https://www.forbes.com/
[75] Yang, P. & Zhang, R. (2020). 'Research on patent of Chinese central cities: From the perspective of cooperative networks', *International Journal of Social Science and Humanity*, 10(4), pp. 108-12.

Beijing is central in achieving the ‘Made in China 2025’ plan that would help the country “leapfrog into emerging technologies and reduce reliance on foreign firms”, including in information technology, robotics, aerospace, maritime engineering, and biopharma.[76] Already home to more than 1,000 AI-based startups, it has one of the highest concentrations of technology entrepreneurs. The total startup ecosystem value is estimated at $345 billion, more than 30 times the global average.[77]

Compared to many cities, Beijing is different in that the state has demonstrated strong willingness to intervene and invest heavily in emerging technologies. It is also interesting how China's geopolitical ambitions and the US-China technological rivalry manifestly influence Beijing’s innovation policies. For instance, the ongoing supply chain disruptions in semiconductor components and Washington’s blacklisting of semiconductor sales to Chinese manufacturers (e.g., ZTE, Huawei) have led China’s Ministry of Education to make semiconductor engineering a priority academic programme.[78] Beijing’s leading universities - Tsinghua University and Peking University - have since established their own semiconductor institutes within mere months. The magnitude and velocity at which state intervention (at the municipal level) influences the development of emerging technologies is worth scrutinizing.

3.3.1 Zhongguancun Science Park

The Zhongguancun Science Park (ZSP) was established in 1988 in the Haidian District of Beijing as a 100km^2 export-oriented industry cluster specializing in the development of emerging technologies. ZSP is widely regarded as one of the core elements in China’s reformed NIS and its “largest intellectual region”;[79] it is also the lynchpin of Beijing’s innovation ecosystem. ZSP grew in scale and significance over the years - from 100km^2 to 488km^2 after 2012, eventually adopting a “one district, multiple parks” development pattern.[80] The science park now houses more than 90 institutions of higher learning, including the world-leading Tsinghua University and Peking University; more than 500 research institutes and laboratories; 1,800 equity investment firms; 22,000 technology companies; 300 R&D headquarters of MNCs.

Numerous studies have investigated ZSP’s success as a high-tech industry cluster, but fewer have analyzed it with an institutional lens. Ordinarily, geographically proximate high-tech companies could benefit from knowledge spillovers, thicker labour markets, and tighter backward/forward linkages. But the *competence* of clusters in generating and retaining new knowledge relies not merely on geographical proximity between firms but on the cluster’s institutional structures. The structures that facilitate/govern the cluster dynamics have a strong bearing on the cluster’s innovation potential. For instance, clusters structured around collective experimentation and learning are generally more technologically dynamic.[81]

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[76] Galston, W. A. (2 March, 2021). ‘Stepping Up The Tech Fight Against China’, *Wall Street Journal*. Retrieved: https://www.wsj.com/articles/stepping-up-the-tech-fight-against-china-11614709490
[77] https://startupgenome.com/ecosystems/beijing
[78] Feng, C. (28 June, 2021). ‘US-China tech war: Mainland universities rush to expand semiconductor programmes in drive for self-sufficiency’, *South China Morning Post*. Retrieved: https://www.scmp.com/tech/tech-trends/article/3139033/
[79] Tan, J. (2006). ‘Growth of industry clusters and innovation: Lessons from Beijing Zhongguancun Science Park’, *Journal of Business Venturing*, 21(6), pp. 827-50.
[80] http://zgcgw.beijing.gov.cn/zgc/zwgk/sfqgk/sfqjs/index.html
[81] Saxenian, A. (1994). *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.

Today, ZSP is more than a network of innovative firms, research institutes and investors. Zhu and Tann describe ZSP as a “knowledge generation system... [and] a system for knowledge dissemination and application, combined with tangible information networks and intangible knowledge networks”.[82] Wang and Wang suggest that one of the most important institutional structures that propelled ZSP to become an innovation powerhouse - especially in its infancy - is the process of spin-offs from state-run research institutes and universities.[83] To commercialize R&D outcomes, academic spin-offs were financially and politically incentivized in the ZSP. These spin-offs were often operated, invested in or jointly/wholly owned by universities and research institutes, ensuring that knowledge transfer continued apace. Technology companies like Lenovo (affiliated with the Chinese Academy of Science) and Founder Group (affiliated with Peking University) emerged through this spin-off process to become the “backbone of Zhongguancun” in its formative years.[84] These early spin-offs provided the entrepreneurial leadership for greater venture building activity in ZSP and inspired the confidence for more researchers to commercialize their ideas.[85]

Chuangxin Pingtai

To organize R&D efforts and realize the innovation potential in ZSP, Beijing established the *chuangxin pingtai* in 2010 to govern innovation.[86] *Chuangxin pingtai* is loosely translated into ‘innovation platform’, but it is better characterized as a ‘joint governance mechanism’ to implement a more ‘systematic pilot policy system’ for testing new innovation policies and initiatives.[87] The *chuangxin pingtai* is anchored by nine working groups that bring together diverse national ministries and local municipal agencies. Its Policy Pilot Working Group, for instance, is led by the Ministry of Science and Technology alongside 13 national-level units and 10 Beijing-affiliated units. The cross-level, multi-departmental institutional format of these working groups integrates both vertically distant (central government and city-level bodies) and horizontally distant (different ministries and functional bodies) stakeholders. This structure provides a forum for different levels and parts of government to work together on specific innovation reforms in a relatively focused and experimental environment, e.g. implementing new equity incentives for academic spin-offs.

Although the agenda of these working groups is explicitly stated at the outset, the open-ended nature of *chuangxin pingtai* allows for the working groups to explore the policy space for non-obvious ideas[88] to promote innovation and emerging technologies within ZSP. By including Beijing-affiliated municipal and private stakeholders, these working groups ensure that the policy formulation process pays more attention to local conditions.

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[82] Zhu, D. & Tann, J. (2005). ‘A regional innovation system in a small-sized region: A clustering model in Zhongguancun Science Park’, *Technology Analysis & Strategic Management,* 17(3), pp. 375-90.
[83] Wang, J. C. & Wang, J. (1998). ‘An analysis of new-tech agglomeration in Beijing: A new industrial district in the making?’, *Environment and Planning*, 30, pp. 681-701.
[84] Lyu, L., Wu, W., Hu, H. & Huang, R. (2017). ‘An evolving regional innovation network: Collaboration among industry, university, and research institution in China’s first technology hub’, *The Journal of Technology Transfer*, 44, pp. 659-80.
[85] Link, A. N. & Scott, J. T. (2003). ‘U.S. science parks: The diffusion of an innovation and its effects on the academic missions of universities’, *International Journal of Industrial Organization*, 21(9), pp. 1323-56.
[86] http://zgcgw.beijing.gov.cn/zgc/sfqgk/cxptjs/index.html
[87] Wang, X. (2016). ‘Intergovernmental relations based on bibilometrics of policy: A case study of Zhongguancun National Innovation Demonstration Zone’, *Public Policy and Administration Research*, 6(11), pp. 83-93.
[88] Prichett, L., Andrews, M. & Woolcock M. (2017). *Building State Capability: Evidence, Analysis, Action*. Oxford University Press.

3.3.2 Beijing Academy of Artificial Intelligence

The Beijing Academy of Artificial Intelligence (BAAI) was established in 2018 as a non-profit research institute to "build Beijing into a leading global AI innovation center".[89] It is also envisioned as a collaborative hub that leverages the research talent and computing resources of leading Chinese AI companies (e.g., Baidu, Megvii, ByteDance), universities, and research institutes. Interestingly, only two of its 7-member Academic Advisory Committee are based in China. The global footprint of its Committee reflects BAAI's global linkages and ambitions to build from Beijing by learning from the world.

Many of the research outcomes are intended to directly benefit the Beijing municipal government. For instance, BAAI developed an intelligent civic assistant for Beijing's Department of Motor Vehicles that would help citizens apply for visas, business permits, and driver's licenses - effectively cutting through bureaucratic red tape.[90] BAAI has also recently engineered a Bluetooth COVID-19 contact tracing application that has been piloted at several offices around ZSP.

Besides developing core AI capabilities, BAAI is also investing in the softer aspects of technology such as AI ethics & safety. It has its own dedicated Research Center for AI Ethics and Safety which published a voluntary code of AI ethics for the Beijing city government,[91] and a set of AI principles to protect the interests of children.[92] Similarly, a BAAI research team published a 'suggested notation for machine learning' that aims to standardize the mathematical notations that AI researchers use to communicate their findings.[93] In doing these, BAAI creates suitable conditions for emerging technologies to thrive safely, while also elevating the city's reputation as a credible and responsible innovation hub.

4. Discussion

Distilling the principles for promoting deep technology innovation

Through the careful analysis of key LIS institutions in three global innovation powerhouses, we begin to see how various LIS strategically create suitable conditions for developing emerging technologies. Three generalizable principles are distilled to help policymakers evaluate their own LIS.

4.1 Mission-oriented innovation programmes

Mission-oriented innovation systems (MIS) formulate clear and ambitious societal goals to steer innovation towards solving these societal challenges. While conventional innovation policies address the market failure in private underinvestment in R&D and exploit positive externalities in innovation networks,[94] MIS goes beyond innovation for economic growth by recognizing the utility of emerging technologies for tackling societal problems. This represents a paradigm shift in innovation policy - developing emerging technologies has the opportunity to not only increase the *rate* of economic

[89] https://www.baai.ac.cn/en
[90] Knight, W. (21 January, 2021). 'This Chinese lab is aiming for big AI breakthroughs', *WIRED*. Retrieved: https://www.wired.com/story/chinese-lab-aiming-big-ai-breakthroughs/
[91] https://www.baai.ac.cn/news/beijing-ai-principles-en.html
[92] https://www.baai.ac.cn/ai-for-children.html
[93] https://notation.baai.ac.cn/en
[94] Hekkert, M. P., Janssen, M., Wesseling, J. H. & Negro, S. O. (2020). 'Mission-oriented innovation systems', *Environmental Innovation and Societal Transitions*, 34, pp. 76-9.

growth, but also the *direction* of this growth.[95] In our analysis, the NYC[x] Moonshot Challenges and the Horizontal Technology Programme Offices at A*STAR are examples of MIS that have adapted to opportunities and constraints in the city. By identifying broad real-world problems experienced by citizens and municipal bodies (e.g., broadband connectivity, food security), these institutions have created arenas in which emerging technologies can be developed, tested and deployed.

However, it is insufficient to simply build mission-oriented innovation programmes, especially at the city-level where testing and deployment of emerging technologies can have many unintended or unforeseen consequences for the community. Policymakers need to think about:

1. How should the mission formulation process be organized? Core to the success of a MIS is the selection of appropriate missions - just as DARPA's program managers select its research agenda or Alphabet's X develops new experimental hypotheses.[96] Local politics and special interests will conceivably influence the mission formulation process, if there is no structured methodology for prioritizing which societal challenges to pursue. Both MOCTO and A*STAR align their mission selection with the prevailing R&D agenda set at the municipal or national level. It is also likely that differences in the societal challenges and technological space might require different types of missions to be launched. To this end, Wanzenböck et al. proposed a two-dimensional problem-solution space to contextualize missions that may be helpful for more nuanced MIS implementations.[97]

2. How should mission-oriented innovation be evaluated? The number of patents, publications and spinoffs are a good indicator for conventional innovation policy, where the objective is to increase the overall innovation output. When solving for societal challenges, it becomes less obvious how cities should monitor and evaluate the quality of missions. One proxy indicator might be the quantity and rate of learning within the institution.[98] Are institutions learning more about the problem space and the possible technological solutions?

3. How would deployment of emerging technologies affect the community? How would the possible solutions interact with existing systems in the city? Mission-oriented challenges aspire to create structural, transformational changes. City governments need to guard against negative consequences and downside risks.

4.2 Granting greater autonomy to public institutions

There is broad consensus that regional autonomy and greater political decentralization are beneficial for cities to discover better ways of doing things, rather than becoming beholden to generic rule sets dictated by a central government.[99] Cities that are able to write "rules-that-change-rules" will be in a stronger position to pursue innovation in a way that works best, given their existing opportunities and

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[95] Mazzucato, M. (2017). *Mission-oriented Innovation Policy: Challenges and Opportunities*. London: University College London.
[96] https://www.wired.co.uk/article/ten-years-of-google-x
[97] Wanzenböck, I., Wesseling, J. H., Frenken, K., Hekkert, M. P. & Weber, M. (2020). 'A framework for mission-oriented innovation policy: Alternative pathways through the problem-solution space', *Science and Public Policy*, 47(4), pp. 474-89.
[98] Chok, L. (2021). *Optimizing Cities for Dynamic Learning*. Charter Cities Institute.
[99] González-López, M. & Asheim, B. T. (2020). *Regions and Innovation Policies in Europe: Learning from the Margins*. Monograph Book.

constraints.[100] Likewise, public institutions responsible for developing emerging technologies benefit from greater autonomy. Developing emerging technologies often require softer regulation and unconventional policies due to their novelty and uncertain unfolding. For instance, it is becoming increasingly uncertain how cities will manage the ethical and safety risks of artificial intelligence products.

Taking a one-size-fits-all approach (e.g., GDPR for data privacy across the EU) across all sectors and geographies may excessively limit the potential of emerging technologies to do good. Instead, public institutions could take the mantle to experiment with new policies to promote, monitor, and regulate the testing and deployment of emerging technologies. BAAI's non-profit, arms-length distance from the municipal government allows it to recommend a code of ethics for AI, while responsively seeking feedback from government, industry and academia. SGInnovate, being a private enterprise wholly owned by the Singapore government, has greater fiduciary flexibility to take high-risk bets on unproven emerging technologies.

4.3 Taking a long-range perspective on innovation

The developmental trajectories of emerging technologies are often unpredictable and in constant flux. City governments should take a long-range perspective that avoids short-termism and availability bias when developing emerging technologies. Institutional structures need not be rigid; on the contrary, well-designed institutions can adaptively respond to new demands posed by emerging technologies. The working group format of ZSP's *chuangxin pingtai* demonstrates the potential for cross-level stakeholders to participate in experimental policymaking, ensuring that innovation policies remain relevant to evolving demands. This has allowed ZSP to remain technologically relevant even though its technological variety has shifted from electronics in the 1980s to software in the early 2000s, and most recently towards artificial intelligence and other emerging technology domains.

Taking a long-range perspective also means cultivating the conditions necessary for early-stage technology experiments to become scalable companies. For instance, SGInnovate and NYCEDC nurture deep tech talent as early as in high school students, thereby increasing the quantity and quality of talent necessary for continued growth of deep technology companies in the next 10-20 years. Similarly, cities can develop auxiliary institutions that carry out foundational work benefitting the development of emerging technologies, which would otherwise not be taken up by private firms because of their low appropriability. BAAI's early work in standardizing mathematical notations in machine learning and MOCTO's municipal IoT "testbed" infrastructure[101] are good examples of this.

5. Conclusion

This paper has carefully analyzed the institutions driving the development of emerging technologies in three global cities: New York City, Singapore, and Beijing. Although the relatively contemporary setup of these institutions prevents robust evaluation, their relative success at creating thriving venture ecosystems gives us confidence to learn from their institutional structures and strategies. Despite the differences in geography and politics among these cities, the public institutions within their LIS are underpinned by very similar operating principles.

[100] Romer, P. (2010). 'Technologies, rules and progress: The case for charter cities',
[101] https://www1.nyc.gov/assets/cto/downloads/iot-strategy/nyc_iot_strategy.pdf

We find that the LIS in these cities is characterized by institutional structures that tolerate the technological risk profile, uncertain development trajectories and local implications of emerging technologies. Through this analysis, this paper has highlighted the value of studying LIS at the city level, as a conceptually distinct system from national or even regional innovation systems. Future work should systematically catalogue the networks and stakeholders that make up the LIS, and further demonstrate how city governments can improve their innovation capacity.