They should also be steeped in deep digital capabilities with significant scope for innovation. In essence, the ideal industries would be appropriately resilient and innovation-intensive.

However, even rearing an economically successful industry may not translate into a mass of high-quality local employment. The fully digital character of some jobs, and the adoption of remote working structures, will disperse high-income jobs across geography.[2]

Singapore must target industries that will generate a healthy base of high-income jobs locally.

Singapore must target industries that will generate a healthy base of high-income jobs locally.

Section 2 then dissects the first shortlisted industry—genomics technology. Singapore has already set up a robust research ecosystem[3]—the crucial next step is to commercialise and shape it into strategic economic engines with export potential. I suggest that the advances in digital technology have poised it for radical transformation.

While it is a science-centric sector, whole-of-economy effects are significant if surrounding policies are sensitive to their potential. Investment must also be directed to adjacent sectors to maximise benefit.

Section 3 explores the space technology industry, and identifies two specific capabilities. I contend that the space technology industry will provide the Singapore economy with a necessary infusion of vibrancy.

Section I: Desired Qualities of Future Industries

Export Potential

Singapore should seek to cultivate industries that have significant export potential. With a small domestic market, Singapore has always depended on trade[4] to survive and prosper.

With growing efforts to reverse global integration, this is particularly challenging. Sluggish economic growth and geopolitical fractures have conspired to entrench

2 The rise of remote working has unshackled output from geography. Offshoring output to high-skilled workers in low-wage countries may be a logical next step for firms, who will keep costly 'on-shore' jobs to a minimum. The gig economy has also revealed how jobs can be atomised into specific functions and outsourced, catalysed by digital technology. Work that is stripped to its component tasks for outsourcing, can then be offshored with greater ease.

3 Singapore set up the Genome Institute of Singapore, under the auspices of the Agency for Science, Technology and Research (A*STAR) in 2000.

4 Trade accounted for 338% of GDP in 2021.

a protectionist agenda among governments across the world, who now seek self-sufficiency instead.[5 6]

Singapore must target industries that can weather protectionism, and deliver strong and stable export growth.

Innovation-Intensive

While tradability is a circumstantial necessity, innovation has always been at the foundation of sustained economic growth in all economies.[7]

Different industries vary in intensity of innovation.

Klevorick et al. (1993) attributed inter-industry differences in innovation to differences in **technological opportunity**[8 9 10], and differences in the ability to **appropriate returns from innovation.**[11]

Singapore should thus **select industries with ample technological opportunity and incentive,** as only innovation can sustainably increase the productive capacity of the economy[12], enable continued economic growth, and create high-paying jobs.

Section II: Genomic Technology

Introduction

Genomic technologies are technologies used in the "manipulation and analysis of genomic information"[13], including genetic sequencing, editing, computing and design.

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[5] The Biden administration recently passed a $465b subsidies programme for green technologies and semiconductors that is "laced with requirements that production should be local". Among them, "roughly half of manufactured components (in) wind, solar and geothermal projects" must be made in America to enjoy higher subsidies. (The Economist, 2023)

[6] In 2020, China unveiled a 'dual-circulation' industrial policy, establishing its strategic desire to localise production, particularly in high-value supply chains.

[7] Economic growth is produced either by brutely increasing the quantity of factor inputs, or by devising more efficient and innovative methods of combining factor inputs. Rosenberg therefore observed that "it is [...] axiomatic that innovative activity has been the single, most important component of long-term economic growth".

[8] In turn, they proposed that technological opportunity is influenced by - 1) the presence of a complementary, formal 'scientific' discipline, 2) advances in other industries , 3) the presence of feedback loops to identify, and ameliorate specific "targets for improvements" in the technological process, otherwise known as "natural trajectories".

[9] The notion of a complementary formal 'scientific' discipline should be construed broadly, especially when understood in the context of the space technology industry which I will discuss subsequently.

In part, digital advances and the proliferation of data have introduced some of the trappings of scientific disciplines, such as tools of measurement, quantification, and precise manipulation. This generates technological opportunity in more unconventional industries. Dosi (2013) recognised the role of instruments (of measurement) in fuelling scientific advances.

For instance, the modern-day financial industry could perhaps be said to enjoy a supporting formal, quasi-scientific discipline in the form of proliferating experiments, academic papers, mathematical equations and tested algorithms that enable more efficient management of money.

[10] Examples of advances in other industries creating technological opportunity could be digital advances catalysing broad-based innovation (e.g. legal technology). It is obvious, however, that some industries (e.g. finance) have benefited more than others (e.g. tourism).

[11] Such as through a patent system.

[12] Productive capacity refers to the maximum possible output of an economy.

[13] As defined by Galas and McCormack Galas An historical perspective on Genomic Technologies. Current issues in molecular biology (2003, October).

By parsing, understanding and acting on human biology at its most fundamental unit, genomics will fuel the next healthcare revolution—from mass therapies to precision medicine.

Genomics is radical because unlike previous scientific advances that extended universal knowledge, genomics illuminates the individual, bridging universal knowledge and individual application.

Economic Opportunities

The promise of genomics thus lies in its ability to **dramatically reduce the informational gap in human health**. If this research is properly translated, it **closes the treatment gap** as well.

In doing so, it can uproot and reshape the healthcare value chain. By enabling diagnosis, prediction and prevention, it averts treatment altogether. Even then, treatments will be customised to maximise efficacy and minimise risks and side effects, rather than being mass-produced.

Regional Genomic Hub

Singapore should become a regional genomic hub. The Genome Institute of Singapore has identified Singapore's ethnic make-up as a competitive asset, given "the presence of three major Asian ethnic groups (Chinese, Indians, and Malays)", all of which are also under-represented in genomic databases.[14]

Singapore should thus compile and analyse local and regional genomic data to better understand pathologies and deliver superior genomic tests and solutions for the Asian population. This data advantage will be self-reinforcing, creating informational superiority that fortifies our genomic hub status.

Additionally, Singapore could provide a 'last-mile' value add for medical providers seeking to penetrate the Asian market. Singapore should thus position itself to offer tailored diagnostic and medical solutions for Asia's emerging middle class.

Genomic Computing & Algorithms

Digital advances have unleashed rich opportunities for genomic computing. Singapore should develop **digital platforms for genomic sequencing, manipulation and editing**. Such underlying technologies are likely to become more lucrative than specific products, because they enable the active integration of the solution with

[14] This opportunity was identified by the Genome Institute of Singapore in its 2030 Strategic Roadmap.

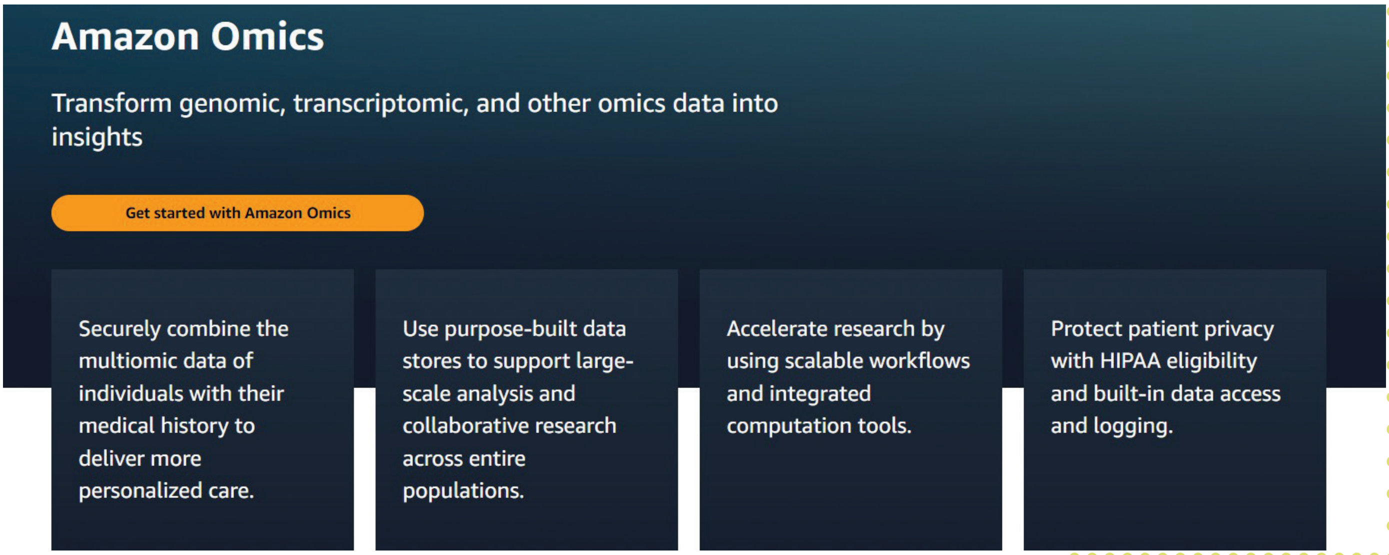

Figure 1: Screenshot from the website of Amazon Omics, which engages in genetic computing. "Amazon Omics helps healthcare and life science organisations build at-scale to store, query, and analyse genomic, transcriptomic, and other omics data. By removing the undifferentiated heavy lifting, you can generate deeper insights from omics data to improve health and advance scientific discoveries."

the individual. This approach also minimises risk associated with specific product development.

Examples include algorithms in AI models that actively calibrate the medical solution to the patient's genetic composition, or genetic tests that provide comprehensive risk profiles and tailored treatment options.[15] Singapore could licence these underlying technologies.

Strategic Alignment

Augmenting Biomedical Research Hub Status

Genomic ambitions mesh with Singapore's existing status as a regional medical hub, and its biomedical excellence. It could leverage on research facilities or financing models. In fact, Singapore has pre-existing genomics research capacity in the form of the Genome Institute of Singapore.

[15] Researchers may develop such algorithms after, for example, gaining insights into correlations as revealed by data analytics. But genetic computing will still demand considerable human innovation in then establishing causal mechanisms and pathologies, and crafting algorithms that reflect this.

Singapore's genomic solutions would offer a high-value source of exports.

Local Healthcare Targets

Cultivating a genomic industry also aligns with Singapore's local healthcare goals —to control costs by focusing on diagnosis and prevention rather than acute care.[16]

High-Value Exports

Singapore's genomic solutions would offer a high-value source of exports. We would export genomic solutions for the regional population, and licence genomic technological platforms, including AI models, that can efficiently produce personalised solutions.

Export Resilience

It is unlikely that protectionism extends to genomic technologies. Even if countries are protective of genomic databases, most cannot muster the finances necessary to develop self-sufficient genomic solutions. It is more probable that the production of generic medicines is 'on-shored'.

Job Creation

Industry growth will also create high-value jobs locally, because the **success of a genomic industry hinges on many country-specific factors**. This includes clear and comprehensive data protection guidelines, a trusted reputation, and existing digital integration within the healthcare system which enables the easy circulation of patient data.[17] Additionally, it requires a legal regime that enforces patent rights and a financial infrastructure to absorb risk and underwrite the development of nascent technologies. Moreover, the specialised machinery in the genomic industry cannot be easily relocated and form a barrier to exit.[18]

The growth of a genomics industry will thus create high-value jobs locally in R&D and healthcare, as well as in our IT, legal and financial sectors, which are necessary for the industry.

[16] The Singapore government introduced the Healthier SG strategy in 2022. It involves "shifting our emphasis from reactively caring for those who are sick, to proactively preventing individuals from falling ill", as extracted from the Healthier SG White Paper. Singapore's ageing population and growing chronic disease burden made this pivot necessary.

[17] In Singapore, this is facilitated by National Registration Identity Card (NRIC) number of every citizen.

[18] "Barriers to exit are obstacles or impediments that prevent a company from exiting a market or industry". Definition extracted from Investopedia.

Policies and Infrastructure

Singapore must radically strengthen efforts to commercialise genomic technologies, fostering a private sector attuned to market incentives. I will borrow Porter's framework of national innovative capacity for analysis.[19]

Input Conditions

Talent is critical to innovation. Singapore should double down on efforts to acquire genomic talent, through global headhunting and bonded scholarship schemes.[20] Incentives could include profit-sharing or spin-off opportunities.

Secondly, given genomics' reliance on data, the hospital system should offer firms access to relevant medical information, and support firms in conducting patient trials to gain better data. Singapore can establish data sharing partnerships with regional states, with high standards to preserve trust.

Next, while A*STAR has existing seed funding programmes, Singapore should attract international venture capital (VC) firms with experience in commercialising medical research to set up funds in Singapore. This could be done through a mixture of incentives, subsidies and tax breaks. Expert VC firms would function as an enlightened sorting mechanism for our local genomics industry, and entice promising start-ups to locate here for capital and tutelage.

Market Context

Singapore should introduce competitive pressures in the genomics industry, first by carefully loosening regulations on foreign genomics products.

We should also augment the profit motive of genomic innovations by developing reliable patent laws around genomics,[21] and inking agreements with other states for cross-border protection of IP rights for genomic innovations.

Lastly, the government should encourage local rivalry by supporting multiple firms even for roughly similar technologies. Porter (1990) has established how local rivalry is uniquely intense and fuels industry growth.[22]

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[19] Porter has suggested that "innovation and the commercialisation of new technologies take place disproportionately in [geographical] clusters", and such activity is influenced by four factors - "the presence of high-quality and specialised inputs, a context that encourages investment coupled with intense local rivalry, pressure and insight gleaned from sophisticated local demand, and the local presence of related and supporting industries".

[20] Scholars can be accorded greater flexibility in serving out their bond across the local genomics industry. This would attract more entrepreneurial talent.

[21] Patent laws should strike a balance between allowing firms to appropriate gains from innovation, and enabling the diffusion of knowledge in a nascent, knowledge-intensive industry.

[22] Porter has argued that "domestic rivalry creates pressure for constant upgrading of the sources of competitive advantage. The presence of domestic competitors automatically cancels the types of advantage that come from simply being in a particular nation—factor costs, access to or preference in the home market, or costs to foreign competitors who import into the market. Companies are forced to move beyond them, and as a result, **gain more sustainable advantages**".

Demand Conditions

Singapore's public healthcare system should be more experimental in integrating and testing genomics solutions, offering "sophisticated" demand that fuels further innovation,[23] and enables firms to continually refine services for commercialisation. The Ministry of Health should subsidise the public hospitals' costs in this regard, as costs of genomic technologies are still high.

Beyond market signals, a formal feedback loop should be formed between hospitals and firms to further aid innovation, arranged by the government.[24]

Supporting Industries

Singapore should also invest in upstream firms that determine the cost and quality of factor components in the genomic industry.[25] The government can broker and finance such joint ventures.

Additionally, Singapore should cluster genomics firms, for co-sharing of facilities to cut costs, and to encourage collaboration.

Section III: Space Technology

Introduction

Space technology is a wide field,[26] ranging from rocket science, to space exploration, to satellite technologies. Unlike genomics, it does not have a basic science of its own.

Yet, it has catalysed advances from the GPS system to water purification techniques. Its breakthroughs in such dissimilar industries demonstrates how the **pursuit of space-worthiness is itself a powerful impetus for innovation**. There is thus considerable technological opportunity in space technology.[27]

The successes of SpaceX, and the prominence of Starlink satellites in the Ukraine war also reflect how the space sector is commercialising quickly—it is no longer the preserve of large states.

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[23] Local hospitals are likely to be "sophisticated" customers given Singapore's world-class medical standards, including the highly advanced health-care and treatments that Singapore hospitals provide.

[24] For example, genomics firms could have staff sited in hospitals, or a task force could be set up with representatives from genomics firms and hospitals.

[25] In this case, it could include chemical engineering, advanced manufacturing, big data and AI development.

[26] As such, while space technology does not have a supporting basic science, one might argue that it has developed a technological paradigm of its own as relatively systematic techniques and objectives emerge. This creates considerable **technological opportunity**.

[27] Refer to discussion of technological opportunity under the chapter 'Innovation-Intensive'.

Economic Opportunities

Satellite Imaging & Remote Sensing

Commercial satellite imaging refers to earth observation, often through small satellites with specialised capabilities. From their extraterrestrial vantage point, they capture whole-of-earth data.[28 29] Such data need not be visual either.[30]

Such data can be exploited to deliver a range of commercial solutions—from pollution monitoring to route mapping for self-driving cars. For example, satellite images could be fed into AI models that influence traffic light signals in a smart city.

When coupled with big data and AI capabilities, satellite imaging will offer firms and nations a radically greater degree of knowledge and control, transforming commercial possibilities.

"They can tell a shipping line—or, soon, an airline—exactly where all its vessels are. They can chart economic growth by recognising the spread of cities and the traffic within them, or the amount of light that they give off at night. They can provide a reinsurance company with daily updates on any changes relevant to its risk portfolio. They can inform futures traders about the state of crops across an entire continent, or individual farmers about the state of crops in a particular field. They can combine their data with other georeferenced data, such as Twitter feeds, to produce images of disasters, demonstrations, conflagrations and celebrations as they happen."

Figure 2: Excerpt on satellite imaging from The Economist Newspaper. (2016). A sudden light. The Economist.

And while national space industries have focused disproportionately on imaging for military purposes, Singapore could **carve a niche in developing specialised, space-worthy sensors with direct commercial application**. Singapore can also develop **digital analytic capabilities associated with such satellite data**, given the specialised interpretation techniques required.

We should also ascend the value chain and develop novel smart city or climate solutions based on satellite data, creating a full-fledged ecosystem around satellite data use.

[28] Market research suggests that the global commercial satellite imaging market will reach $8.77 Billion by 2030 and at an 11.2% compound annual growth rate.
[29] Practically, this could include tracking plane routes, detecting rainforest damage, or monitoring carbon emissions.
[30] Local small-and-medium enterprise Lighthaus, for instance, has developed optical telescopes and hyperspectral cameras to capture the spectral power distribution of light.

Operational Satellites by Type	Number of Satellites	Percentage of Operational Satellites
Commercial	1440	54%
Government	436	16%
Military	339	13%
Civil	133	5%
Combination (Other)	112	4%
Combination (Commercial)	206	8%
Defunct Satellites	**3200**	

Figure 3: The majority of satellites in space are commercial satellites. There were also 2,304 small satellites launched in 2022. Chart extracted from the website of the World Economic Forum.

Components for Small Satellites

With costs falling, small commercial satellites are proliferating.

Singapore is well-poised to provide the mechanical and computing components for them, given our expertise in advanced manufacturing, aviation, and computing.

This will form the **technical foundation** of our space technology ecosystem.

Apart from direct application, manufacturing space-faring objects will inject considerable vibrancy into our economy, because the operating conditions of terrestrial and celestial products are radically different. The vast array of innovations that space-faring programmes have already catalysed is testament to the g**enerative potential of seeking space-worthiness**. This experimental process will thus yield unanticipated spillover benefits.

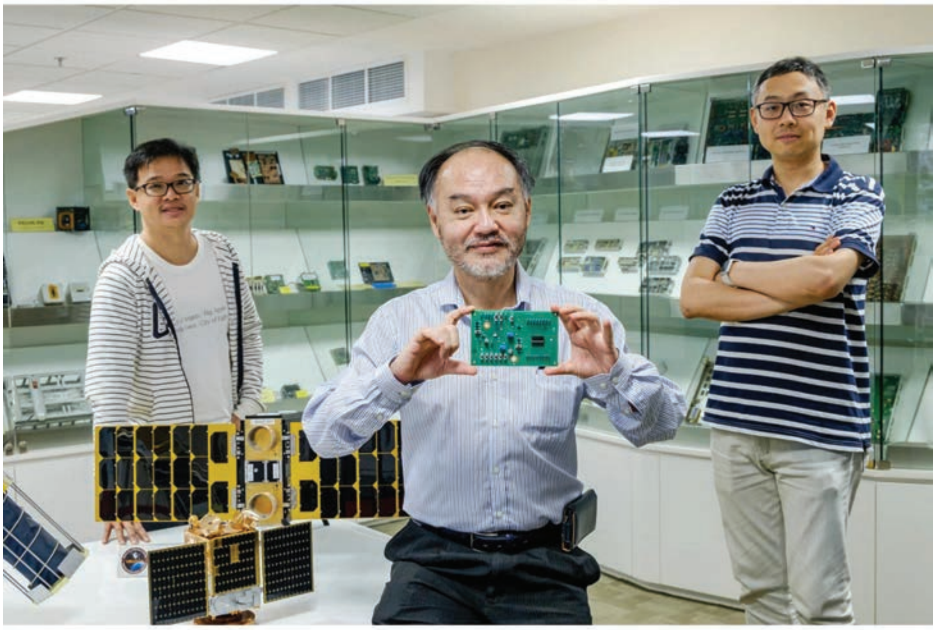
Strategic Alignment

Bolstering Key Economic Pillars

Satellite imagery efforts will further nuance our big data and AI push, and will enhance the value of our **urban and climate solutions**, which are strategic national priorities.[31]

[31] Singapore seeks to become a smart city, as part of a broader Smart Nation effort. Smart sensors to optimise infrastructure, for instance, will be a smart city feature. Satellite data can augment this, or even entirely supplant inferior data sources.

For instance, local start-up Zero-Error Systems was founded by veterans from the semiconductor industry. They observed that more satellite manufacturers use commercial semiconductor devices that are not designed to thrive in space. To close this gap, the start-up developed radiation-hardened electronics to protect the devices and extend satellites' lifespan.



Professor Joseph Chang (centre) of Nanyang Technological University holding the Latchup Detection and Protection chip launched by Zero-Error Systems (ZES). With him are Dr Chong Kwen Siong (left), ZES' co-founder, and Dr Shu Wei, ZES' chief technology officer. PHOTO: NTU

Figure 4: A small satellite component developed by local researchers, extracted from *The Straits Times.*

Our advanced manufacturing of small satellite components will add to the resilience and vitality of our advanced manufacturing sector, bolstering broader sector competitiveness in the long run.

The space technology sector also aligns with Singapore's other strengths such as aviation and mechanical engineering.

High Value and Resilient Exports

Exports include highly specialised products which capture and process satellite data, with niches in climate and urban solutions. Technological platforms for data integration can be licensed. If proactively embedded in commercial platforms, such products and services would be more resilient.

With anticipated growth in demand for small satellites, advanced manufacturing of its components will also enjoy strong derived demand internationally.

Job Creation

The development of a local space sector will create a healthy volume of local R&D and advanced manufacturing jobs. Downstream job creation can be expected in the IT industry due to reliance on big data, AI and computing capabilities.[32 33]

Policies and Infrastructure

Unlike genomics, the challenge here is not so much in commercialisation of capabilities, but more so in funnelling resources to promising domains of space technology.

Input Conditions

As space technology is not a basic science, research talent is limited. While a space technology academic degree may not yet be feasible, the NUS' Specialisation in Space Technology programme is a step in the right direction.[34] Universities should attach space technology specialisations to more physics and engineering degrees. This would spur further academic interest, and create a pipeline of space technology talent.

For institutional knowledge creation, A*STAR could form a space technology centre, but with explicit areas of focus specified (e.g. satellite optics and sensors) so as to achieve genuine innovative depth despite it not being a basic science. It could form partnerships with larger space industries like those of the US, Japan and France, for transfer of knowledge.[35]

Market Context

Even if our local environment is conducive, space technology is ultimately utilised in outer space, where jurisdictional dilemmas are rife. Singapore must advance multilateral discussion of legal principles surrounding outer space, to ensure the extraterrestrial protection of property rights and patents.[36]

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[32] As with the genomics industry, given the specialised technological facilities required, most job creation is likely to be local.

[33] Naturally, if Singapore does manage to provide all services along the satellite data value chain, it may be considerably more enticing for foreign firms to relocate here to take advantage of this, further adding to employment.

[34] This programme seeks to "equip students for satellite related industries and many other industries such as aerospace, automotive and all the related commercial products", based on the NUS College of Design and Engineering website.

[35] As with the genomics industry, the government should establish funding mechanisms, particularly for projects with commercial application, as a source of risk capital for the industry. The government could also consider spreading funds to firms across the value chain to help the industry become self-sufficient more quickly.

[36] As with the genomics industry, the government should sign mutual agreements to respect space-related IP, particularly with significant players in the space industry, giving firms incentive to base innovation here.

> The development of a local space sector will create a healthy volume of local R&D and advanced manufacturing jobs.

Demand Conditions

Agencies like the EDB and Enterprise SG have deep industry networks, and should encourage local firms to consider utilising relevant space technology services, such as image analysis, through subsidising such ventures. This offers both a customer base and "sophisticated" demand for space firms to attune themselves to commercial needs.

Given its alignment with national climate and urban priorities, relevant government departments could collaborate closely with space technology firms to embed the use of their platforms in national plans. This would provide firms with an early source of demand, reducing the risk of entrepreneurship.

Supporting Industries

Space technology firms and suppliers should be co-located, in a set-up similar to the Biopolis. Such cluster co-location could help to reduce costs of facilities like simulators through sharing. Proximity to suppliers enables R&D testing.

Section III: Conclusion

Both the genomic and space technology promise to transform Singapore into an R&D hub and much more vibrant economy altogether. Singapore should be confident in the fact that it enjoys a highly-skilled workforce and strong R&D capacities to make this crucial leap that will sustain its economy into the future.

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