Comparing the Participation of National Science and Technology Research-Intensive Universities in Defense Industrial Sectors

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by

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Abstract

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This thesis compares how leading science and technology universities can participate and interact with countries' defense industrial sectors. Implicit to this aim, we are looking at successful models for such leading institutions to make meaningful contributions to countries' efforts at maintaining modern and efficient defense industrial sectors. To this end, the thesis looks at and compares leading universities in Singapore and South Korea and seeks to uncover the extent to which they participate in their respective nations' defense industry efforts and, in particular, how they aid attempts at producing critical national security technologies.

The thesis employs a comparative approach, utilizing publicly available data to understand the areas of collaboration and involvement of national science and technology leading universities with domestic defense industries. The thesis selected leading universities in South Korea, including the Korea Advanced Institute of Science and Technology (KAIST), and Singapore, including the Nanyang Technological University (NTU) and the National University of Singapore (NUS), to make a detailed comparison. This research aims to look at the level of influence by governments or industries – specifically, the defense sector – on the University's R&D centers and the level of integration between these institutions and the defense industrial sector. The thesis looks particularly at the extent to which university Research and Development (R&D) centers are orientated towards defense sector needs and assist and participate in shaping the existing defense sector (in both South Korea and Singapore).

Indexing Terms: defense industry; university; collaboration

Declaration and Copyright

Declaration

I declare that the work in this thesis was carried out in accordance with the regulations of Khalifa University of Science and Technology. The work is entirely my own except were indicated by special reference in the text. Any views expressed in the thesis are those of the author and in no way represent those of Khalifa University of Science and Technology. No part of the thesis has been presented to any other university for any degree.

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Chapter 1: Introduction

1.1. Context to the topic and research problem description

The global concept of war has changed, yet it has not been eliminated. Traditionally, war is defined as a state-on-state conflict between organized, uniformed, professional military forces using massed firepower in open space away from civilians to destroy each other. It aims to gain and hold territory, as power was defined by the territorial and geographical spread of one's authority. Nowadays, this definition or form of war is rare. Nonetheless, states live in the perpetual state of anarchy in a world where war – however, defined – and other security challenges proliferate. States, and the leaders acting on their behalf, must strive to maintain the capability to produce armaments for their protection and national security needs. Access to foreign weapons and tools is one-way states can arm themselves but leaves them vulnerable to supplies being cut off. The increased access is troubling as reliance on the imports of foreign high-tech defense products can be unpredictable in the long run due to the dynamic nature of foreign affairs and politics. Countries need to reach some level of independence or a high ratio of individuality by developing local military capabilities to deter aggression from becoming independent. Entailing trust in local capabilities to deliver desired outputs. Many states thus often prefer to produce their armaments and cutting-edge national security-related technologies but struggle to do so.

One of the biggest challenges is fostering the national technological ecosystem needed to produce the underlying technologies, knowledge, and expertise to domestically produce weapons and other national security-related technologies, such as drones, secure communication technologies, sensors for a range of intelligence, surveillance, and reconnaissance platforms (including satellites), and much else besides. Self-reliance in some areas of armament production demands developing local capabilities and skills in multiple fields and sectors. Therefore, many governments directly fund, provide tax incentives, or assign/establish grant-providing agencies to R&D centers at universities to encourage research and innovative solutions applicable to different industries, including the defense industry. The key aim is to build a resilient defensive system locally and utilize such capabilities and innovations to strengthen the local economy through global market trade.

This initiative fully utilizes publicly owned R&D centers and research-intensive universities, increasing local capabilities, knowledge integration, and industry involvement. It also reduces the financial burden of adopting new research proposals and purchasing high-tech defense products from unpredictable international markets. In this regard, local industries under different sectors (i.e., health, defense, security, energy, etc.) are allocating more of their budget to R&D centers and research-intensive universities.

Universities and R&D centers must exert a level of influence given the role, and trust governments give them to develop their defense sector. This paper looks at the role national research-intensive universities play in a country's defense innovation ecosystem by undertaking a comparative dual case study of two modern examples: Singapore & South Korea. Both nations have globally competitive domestic defense industries that furnish their armed forces with modern weapons systems and provide an economic gain by selling defense solutions internationally. Their arguable success is believed to be in no small part due to the role played by research-intensive universities in their national defense ecosystems.

Research-intensive universities have influenced, assisted, and participated in the domestic defense sector development and progression in various settings. This thesis compares universities' current and past experiences in Singapore and South Korea with their respective national defense industrial efforts. The findings may have significance for the United Arab Emirates and its national champion research-intensive university – Khalifa University. It is essential to understand the possibilities in front of the university and its potential position in the industrial defense strategy and its broader defense innovation ecosystem. Moreover, the study will provide us with broader inferences of possible areas of collaboration and available opportunities connecting academia and the defense industrial sector that have applicability beyond the cases examined.

1.2. Problem statement and its significance

Countries constantly need to develop their military capabilities and compete internationally to deter aggression and possible violence. Reliance on the imports of foreign high-tech defense products can be unpredictable in the long run and vulnerable to embargos by exporting states. Perhaps now more

than ever, governments realize the importance of local arms manufacturers and tailored defense solutions for reaching independence. For example, the recent Ukrainian-Russian conflict exposed a shortage in military equipment and solutions required to retaliate against the Russians. It demonstrated Ukraine's reliance on outside sources of arms and other national security capabilities such as satellite imagery. Several countries and organizations like NATO pledged to send military aid to Ukraine. However, the issue relies on whether the aid will arrive on time for the Ukrainians to utilize against the Russians. Not only that but also whether the stream of imports will continue. The uncertainty accompanied by the element of surprise pushes countries to achieve independence, as neglecting it causes a security vacuum and long-term security threat. Therefore, governments are incentivizing R&D centers and sponsoring university programs to enrich the defense industry.

Nevertheless, how does this relationship – research-intensive universities and the defense industrial sector – work in practice? More particularly, how does this relationship function in settings with high levels of state intervention in the defense sector where most activity is government-led and funded (such as South Korea, Singapore, and the UAE)? This research problem is what this thesis seeks to tackle.

1.3. Research objectives

1.3.1. Statement of research aims

The research aims to understand the defense industry structure and the role played by national science and technology research-intensive universities in influencing and assisting the defense sector. It seeks to understand the factors that underpin the inter-relationship, the level of influence and participation in different settings, and how this two-way relationship operates. The aim implicit within this objective is to locate some of the mechanisms by which these research-intensive universities can play a meaningful and worthwhile role in their countries' defense-industrial enterprises.

1.3.2. Research question including type of question

To what extent and in what ways do national research-intensive universities influence, assist, and participate in countries’ defense innovation ecosystem?

Type of question: Exploratory

1.3.3.Research hypotheses

Although this is an exploratory research agenda, the thesis puts forward possible expectations, or hypotheses, that it will use to direct and guide findings and subsequent discussion of those findings.

Hypothesis 1: *The character of a country's defense industrial sector (its relative maturity, structure, and scope) profoundly shapes the role research-intensive universities play in a country's defense innovation ecosystem.*

Hypothesis 2: *The level of state control, funding, and intervention in higher education and defense sectors are crucial. The higher state intervention, the more likely there is a symbiotic relationship between research-intensive national universities and the defense industrial ecosystem.*

1.3.4.Variables, concepts, and indicators

Dependent variable:

- The extent of the relationship and level of integration between national research-intensive universities and the defense industrial sector.

Independent variables:

- The character of a country's defense industrial sector (from hypothesis 1).
- Level of state control, funding, and intervention in higher education and defense sectors (from hypothesis 2).

Concepts:

To understand the role of research-intensive universities in a country's defense industrial sector, we need to find ways to measure the key variables.

- Locating the presence or absence of government-sponsored defense R&D centers in the university.
- Locating the presence or absence of policies at the university to act as a talent pipeline for the defense-industrial enterprise.
- Locating the presence or absence of defense technology aims or charters in founding the national research-intensive university.

As for the first independent variable (character of a country's defense industrial sector), this will be qualitatively described according to the following criteria:

- *Maturity* – How long the country has pursued domestic defense industrial efforts.
- *Structure* – Relative proportion of private-public sector involvement and international collaboration versus domestic companies.
- *Scope* – Size and ambition of domestic defense industrial sector.

Measurement:

The thesis relies on information in the public domain to measure the indicators and attempt to validate or invalidate the hypotheses. More will be divulged about this in the methodology sector but suffice it to say here that this approach has some limitations as it does not involve primary data sources within the countries that comprise the comparative case study. This limitation is offset by the relative availability of information in the public domain. Of course, many countries keep information about defense technologies secret. The aim here, however, is not to try and uncover details about unique collaborations between a university R&D center and a government defense program; the thesis is simply interested in painting the overall picture.

1.4. Structure of the thesis

Chapter 1: introduction

- Context to the Topic
- Problem Statement and its significance
- Research question including the type of question
- Research hypothesis
- Variables, concepts, and/or indicators
- Thesis project stages
- Structure (of the thesis)

Chapter 2: Literature Review

- Peer-reviewed articles, books, and journals are written by scholars and researchers that discuss University research centers, academic researchers' industry involvement, and how

different types of University Research Centers Impact Individual-Level University-Industry Interactions.

Chapter 3: Research Methodology and Research Methods

- This paper will use a paired comparison research approach to clarify the nature between national research-intensive universities and – in this case – the defense industry.
- Singapore and South Korea have been selected as case studies as they vary on at least one of the key independent variables – the character of their respective defense industries.

Chapter 4: The Results

- The expected result of this paper is to identify the pattern and the correlation between industry sponsorship and the University research center's scope of work. This should help us understand the influence exerted on R&D centers by sponsors and roughly identify if R&D centers are guided by clients "Client-based" or Science "Science-based."

Chapter 5: Discussion

- This section will discuss the key findings of the paper based on the literature review and the analysis of content and discourse. Also, we will try to connect the finding with the theoretical framework.

Chapter 6: Conclusion

- This chapter will summarize the key insights of the thesis and map out some further research studies that extend my study in some essential areas.

Appendices

- A list of definitions, abbreviations, and acronyms.
- All references used in this paper are in APA citation style.

Chapter 2. Academic Literature Review

A central role of universities globally is to spearhead the progress of institutions, governments, communities, and markets through organized research and development innovations and projects. According to Boardman (2009), universities are expected to partner with other educational organizations and governments as part of their research and development efforts. These partnerships have informed the growth of economies and contributed to how nations globally have modernized their defense sector from the significant scientific and technological breakthroughs of university research centers. Historically, the degree to which the defense sector can influence, participate, and assist in driving national science and technology university research centers was first extensively tested during the Second World War.

Geiger (1992) notes that during the period beginning in 1945, most governments across the globe intensified their support for research and developments in universities as a means of equipping their national defense capability and improving their ability to participate and win in ongoing global conflicts. Geiger (1992) reports that in the 1940s and 1950s, governments, such as the US, supported university R&D projects with up to 96% of the budget. The financial support allowed most universities to upgrade their staff and hire other specialists in unique defense-related fields such as nuclear science, as shown by Dong-Won and Leslie (1998). However, it also meant that the armed services became the primary stakeholders for the higher education institutions. In the US and the west, for example, the growing tension that had begun during the Second World War and continued to the cold war era allowed governments to increase their spending on the development of nuclear and other types of war technology in the university research and development labs. Thus, most of the projects and interests that did not directly contribute to the defense sector were either left dormant or abandoned by the universities at the government's request. Such exercise of influence and power in driving the R&D activities of local universities resulted in scholars and researchers opposing the government. The growing tension between the government wanting only to find specific defense-oriented projects and universities seeking to have their independence as learning and R&D institutions led to changes over time.

In the US, the changes that occurred provided for the defense sectors through NASA and the military services to continue working with universities while also allowing the educational institutions to have a certain degree of independence (Geiger, 1992). In particular, one of the arguments that the government offered to explain the continued collaboration was the need to develop peace-time research and technology that would not only promote the modernization of the defense sector but also profit the universities and other aspects of society (Geiger, 1992; Smart, 2016). For example, Turse (2004) points out that the modern military-academia complex is a hybrid of two inter-related and inter-dependent systems. The first is the pure military academies, which are universities specifically established to research and develop war and wartime technology and innovations. Such academies are entirely operated and funded by the government. The second part of the military-academia complex is made of civilian universities, most of which are contracted to innovate technology and other R&D projects to support and strengthen the modernization of the defense sector while continuing to carry out other educational activities independently.

Interestingly, despite the changes in the interaction between world governments and the defense sector, how the two institutions influence each other has not changed. For instance, (Smart, 2016) reports that as early as 1862, the US military had engaged local universities using the Morrill Land-College Act to help develop innovations and mechanical research arts and agriculture for the armed services. Then, the government used money/ budgetary allocation and the formulation of policies to safeguard the military-academia complex. Later, with scholars and analysis calling for the independence of the education institutions, universities such as Columbia University, Harvard University, the California Institute of Technology, and the Massachusetts Institute of Technology continue to develop highly specialized technology and science projects for the defense sector under the lure of ready financial support and national/ federal policies prioritizing national security (Smart, 2016; Turse, 2004).

Notably, the military and defense sector's interactions and influence on local universities in the west would soon become the blueprint through which other second and third-world nations would also strengthen their military, economic, and political might globally. For example, South Korea is one of the nations that rose into the political, economic, and security limelight in the 1990s due to the

interaction and relationship the government developed with local science and technology universities. For South Korea, the elite political class used the blueprint developed by western nations of using policy frameworks and financial influence to establish new or contract existing universities to focus on developing technology and science innovations for the defense sector. For instance, Dong-Won and Leslie (1998) observe that the rise of South Korea in the 1990s was primarily a function of the growth of university-driven research and development programs and the partnerships that the government formed with the education institutions. For instance, South Korea began by creating the KAIST (Korean advanced institute of science and technology) as pioneering research and development-driven institution.

In particular, Dong-Won and Leslie (1998) argue that the government established KAIST primarily to facilitate sharing of technology, scientific innovations, and research with other governments, including the US. Later, when the US needed South Korea to participate in the Vietnam War as an ally, KAIST was further upgraded to focus on developments that would strengthen the nation's defense sector. In South Korea's case, the defense sector's modernization through the R&D activities spearheaded by local universities was achieved by the government's promotion of a dense policy characterized by interdependence, independence, and subsidy. Interdependence allowed the government to finance local universities to focus on innovations and research that would strengthen and modernize the defense sector. The independence allowed the local universities to be self-sustaining, which meant they could partner with other research entities and governments and exchange innovative knowledge that ultimately benefited the Korean government's defense R&D strategies. Lastly, subsidies, instead of complete financing of all local university R&D research projects, meant that the educational institutions had to develop dual-usage technologies (technology that would benefit the government and the defense sector while also profiting the universities).

However, the avenues and approaches South Korea and the US governments used to influence, assist, and coerce universities to focus on R&D activities to modernize the national defense sector have also changed over the last few decades. For example, following the scholarly protests of the 1990s, most governments allowed the local universities to have significant control over the research types done besides those directly requested by the defense sector. The consequence of the

neoliberal movement in universities in terms of its effect on the modernization of the defense sector was two-fold. On the one hand, the increased liberty meant that university professors and scholars could use the financial support from the government to develop other non-defense-related R&D projects. However, since the government was still funding the project, later policies focused on pressuring the universities to offer military or defense-related courses in civilian universities. In the US, for example, part of the financial support from the government was directed toward establishing and developing various engineering courses (Association of American Universities, 2013). These courses include metallurgy and material engineering, mechanical engineering, aeronautical engineering, astronautically engineering, and electrical engineering. While such courses have value for the universities and students in the civilian labor market, they also are essential in furthering the skill and capacity of the defense sector. In some cases, the government has directed universities to integrate elements of defense such as the development of shielding and security features as part of the engineering courses, thereby benefiting directly from their investments in university-driven R&D. Moreover, besides the financial support of specific courses that have civilian and defense values, governments have also utilized the neoliberal-inspired university R&D by expanding the traditional courses offered in the institutions to have military applications (Smart, 2016). For instance, most universities that receive financial support from the government for R&D have directed the capital towards supporting social and anthropological studies. Traditionally, such research areas have been of little interest to the defense sector (Smart, 2016). Instead, it was focused on technology and science-based R&D. However, in the wake of changing global war landscape, defense-related institutions such as the CIA have funded local universities to conduct social and anthropological investigations. The results of these investigations can be used to provide the military service agencies with knowledge of behavior and socialization that is deemed helpful in promoting national security. This new approach is similar to the peace-time strategy that governments used in the 1950s to convince universities to partner with the defense sector through research and development to develop new technology and innovations for national security. However, under the new dispensation where social sciences and anthropology are considered scientific fields for universities to conduct R&D to modernize the defense sector, the motivation provided is that understanding aspects such as culture,

social values and norms, religion, and language are essential in not only strengthening the national defense but also promoting internal diplomacy (Association of American Universities, 2013).

In conclusion, the modernization of the defense sector through local universities' research and development had continued to evolve since the Second World War, when the military-university complex began expanding. Throughout the history of the association between the defense sector and universities, several aspects have remained. For instance, the government still relies on funding and public policy as the main approaches to enticing, influencing, and encouraging local universities to conduct R&D to benefit the defense sector. Moreover, even with changes in policy to allow universities more freedom in doing other scholarly research and development projects, those funded by the defense sector are still prioritized.

Chapter 3. Research Methodology & Research Methods

This thesis employs a comparative case study approach to the research problem by looking at Singapore and South Korea and the role of their research-intensive universities in their respective defense industrial sectors. The findings are then applied to the UAE setting, particularly the prospects and possibilities for the country's chief research-intensive university (Khalifa University) to participate and contribute to the nation's national security technology goals.

3.1. Overall research design

This thesis employs a paired comparative case study approach to the research problem. This way, it comprises a small-N study to identify, analyze, and explain similarities and differences relevant to the variables across two settings (Hantrais, 1995). Paired comparison is a form of analysis used extensively in political science research. It is a distinct strategy of comparative analysis with advantages that both single-case and multi-case comparisons have deficiencies.

3.2. Methodology

The study uses a Qualitative Comparative Analysis (QCA) approach, examining paired cases in detail while looking at how the different parts of a case fit together, both contextually and historically. To make a detailed comparison, I have selected South Korea and Singapore.

The approach assists the thesis in testing the two hypotheses and detecting different configuration that results in similar outcomes. Moreover, it helps to understand, explore, and test our theory related to the role played by universities in the defense-industrial enterprise and allows the development of linkages between the indicators and the measures in place and explore any patterns or trends.

3.3. Methods including limitations

3.3.1.Methods

We used a mixed-methods research approach because it generated the desired outcome. The term “mixed methods” refers to an emergent methodology of research that advances the systematic integration, or “mixing,” of quantitative and qualitative data within a single investigation or sustained

program of inquiry (Wisdom & Creswell, 2013). We utilized quantitative data to enhance and strengthen our findings from our qualitative data by applying qualitative comparative analysis (intermediate N) methods to draw insights from the literature. The method allowed us to explore the Defense industry - University R&D interaction and conclude the factors that have shaped their current research field.

3.3.2.Data Sources

Both Singapore and South Korea are open societies relative to international standards. Their government bureaucracies and public universities publish considerable data and information about their budgets and activities. The study utilizes a range of information that this in the public domain. Some research in the defense and national security sectors remain, by necessity, "behind closed doors." However, this limitation does not bias the overall findings, given the wealth of publicly available data.

3.4. Limitations

3.4.1.Validity

Validity refers to the validity of the measure selected to test the research hypothesis, and it depends upon how we define the concept. In social sciences, there are no specific definitions of the terminologies. Therefore, researchers try to assess the measure using multiple ways to justify their approach (Halperin & Heath, 2017). We evaluated our measure based on face validity and content validity. Face validity indicates that the indicators intuitively seem like a good measure of the concept. For instance, understanding the percentage of research sponsored by the defense sector vs. non-sponsored research will give us an idea of the level of influence exerted by the defense sector. If the number of sponsored research centers and publications increases, that will indicate the importance of research and development centers to the government/defense sector, provide a rough image of the direction of the defense sector, might raise the question of the importance of other sectors due to resource allocation (limited resources).

This paper provided an external validity where the conclusions can be generalized to the broader population. A set of measures are in place to ensure validity whenever possible such as random samples, appropriate sample sizes, no biases, not influenced by funding or the desire to seek specific results—our research. Our sample selection was based on reachability, connections, and ability to access information on time. The sample size is relatively small due to timeframe restrictions. However, this allows more research to be built with a bigger sample size in the future. The research is not funded whatsoever. Therefore, biases to achieve a particular outcome are out of the question.

3.4.2.Reliability

Reliability is the accuracy of the data or findings based on the instruments or tools in use, yielding consistently the same results on repeated occasions. The study considers the Korea Advanced Institute of Science and Technology (KAIST) as a unit of analysis from South Korea and Nanyang Technological University (NTU) for Singapore as a sample design to gather primary data via a set of approved interviews. However, this was not the case, as we could not reach multiple people for an interview due to time constraints. Therefore, the data gathered were obtained through secondary data and official governmental organizations, whether KAIST, NTU, or any alternative data center. There is a possibility for biases, as competition does exist between universities and numbers, or achievements might be exaggerated to a degree. Therefore, we have benched marked the data provided through the websites with other data-providing agencies to confirm our findings. Another major limitation is repeatability. Repeatability means the likelihood of reproducing similar results at any given time is granted (Mackenzie, 2019). Fortunately, this is the case because most information is available online through official sites and governmental archives.

3.4.3.Generalizability

Generalizability refers to the ability to implement the current findings of a study on a broader group, situation, area, (Myers, 2000). The study gave us a general understanding of the structure of R&D centers in developed countries. It allowed us to explore influential factors and patterns in navigating Universities/ operations regarding their R&D funding and research topics in developed countries. The primary limitation to the generalization of these results is the shortage of research and development

facilities in the Arab Region, the UAE, and other Gulf Countries that can utilize the research to learn about the impact of R&D centers in the development of the defense sector, long-term wealth generation, economic growth, and technological independence. The UAE does have the funds to invest in R&D and the infrastructure and can teach, build, and develop its academic pool.

Chapter 4. Results

4.1. Case One: Singapore

4.1.1. Background of Singapore politics and economy

Singapore was founded in 1965 in a territory of barely 581.5 km2 and a population of 1.8m, all migrants with different religions, ethnicities, and languages (Cornell University, INSEAD, World Intellectual Property Organization (CIWIPO), 2016). It is impossible to forecast its current success as Singapore has very few natural resources, limited agriculture, a lump sum 10% unemployment rate, and little to no education and health care access (CIWIPO, 2016).

After Singapore's independence from the British, the Japanese occupation during World War II, and the rising interest of neighboring countries in proclaiming Singaporean lands, Singapore was determined to build itself as a regional power (Mondeja, 2017). It begins with establishing compulsory military service for Singaporeans, signing peace treaties with neighboring countries and great powers, building and maintaining diplomatic relations with more than 189 countries, as well as, joining an international organization such as the United Nations and the Commonwealth of Nations, and co-founding the Association of Southeast Asian Nations (ASEAN) (Mondeja, 2017). All in efforts to protect its sovereignty, prolong peace, and promote socio-cultural, economic, and political advancement and cooperation (Mondeja, 2017).

Singapore is a land with significantly few natural resources (CIWIPO, 2016). This places it in a very tough spot for economic growth and development (CIWIPO, 2016). Singapore had to bring forward an alternative strategy for economic transformation (Mondeja, 2017). Like any other developing nation, Singapore borrowed loans from the World Bank to kick start its series of advancements (World Bank, 2019). The first loan was provided in 1963 under the guarantee of the UK Government. The Malaysian Federation (*to which it then belonged*) and the remaining loan arrangements were provided for Singapore after its independence (World Bank, 2019). Loan allocations were prioritized based on the recommendations of the World Bank analysis in 1963 (World Bank, 2019). Loans were initially allocated to building resilience infrastructure sectors (*i.e., water interconnection, port expansion, sewage, power, and telecommunications*) as they are

considered one of the most critical aspects of Singapore's economic future in the long run (World Bank, 2019). Then shifted into investing in human capital and the services sector (*i.e., environmental management programs and the development of the national university*) (World Bank, 2019). By the mid-1980s, the loans were repaid. Singapore had to compete with low-wage countries and amend or copy some of its economic policies to float (Zarroli, 2015). However, those early steps have transformed Singapore into a major manufacturing and financial center with complete economic freedom, including low taxes, few capital restrictions, and liberal immigration policies, making it one of the most cosmopolitan places on Earth (Zarroli, 2015). Other sectors adding to Singapore's economy include electronics and precision engineering, information and communications, and finance & insurance industries (Zarroli, 2015).

4.1.2.Maturity, Structure, and Scope of Singapore's Defense Industrial Sector

The defense industry includes all public and private firms that are commercially involved in the research and development, engineering, design, production, delivery, and maintenance of military weapon systems, subsystems, and components or parts according to the military requirements (CISA). All firms perform under contract to the Singaporean Department of Defense and provide products and services to the Department of Defense and government-owned/government-operated facilities essential to mobilize, deploy and sustain military operations (CISA).

Maturity

The establishment of the Singaporean defense sector can be traced back to 1965, following the independence of Singapore from the Malaysian Federation amidst the Indonesian–Malaysian Confrontation, which was, in fact, an armed conflict (Andrew , 2013). The country was surrounded by two large countries in conflict, with no military capabilities to speak of nor strong diplomatic ties backing its position (Andrew , 2013). The high tension and political instability drove Singapore to establish its defense-industrial sector a high priority (Andrew , 2013). Therefore, Singapore's defense industrial sector has a half-century heritage. It is important to note that research was not prioritized, and little to no investment was allocated. Singapore has countless research hubs and institutes, such as

the National University of Singapore, Nanyang Technological University, and the Agency for Science, Technology, and Research (A*STAR) (Andrew , 2013).

Structure

In Singapore, the structure for funding research and development in defense is heavily systemized. The overall research funding process has been coordinated, organized, and managed by the National Research Foundation since 1991[1] (National Research Foundation (NRF), 2021). Every five years, the NRF sets out Research, Innovation, and Enterprise (RIE)[2] Plan in strategic areas of national relevance to address national needs, prepare for future challenges, and generate new opportunities for growth (NRF, 2021). The plan focuses on research areas for the next five years and the budgetary needs accordingly. Moreover, the NRF budgets unforeseeable or unanticipated needs and opportunities and places them under "White Space" (NRF, 2021).

Since the country is small and has limited resources, funding cannot be allocated or distributed randomly (NRF, 2021). Therefore, direct funding from institutions to universities or research centers in Singapore does not exist (Wong & Kannan). All funds from various funding agencies and bodies (*local or international*) must go through the RIE (NRF, 2021). The RIE comprises various ministries, R&D funding bodies, and R&D performers, including Trade and Industry, Education, Health, Defense, and other Ministries and Agencies. Each ministry is responsible for an R&D funding body and an R&D performer (*see figure 2: Ministries, R&D funding bodies, and R&D performers*) (NRF, 2021).

There is some influence from the research community on funds allocation or the policy-making process (Wong & Kannan). Typically, funding bodies arrange workshops and consultative sessions with thought-leaders, key researchers, and eligible institutions showcasing current grants and new grants to hear their feedback, understand existing gaps, and draft a better framework to cater to

[1] The National Research Foundation (NRF) is a Prime Minister's Office Department. Responsible for formulating 5-year plans and policies to grow Singapore's research capability, support economic growth, and meet Singapore's future national challenges.

[2] Research, Innovation and Enterprise Council (RIEC), chaired by the Prime Minister, oversees the long-term research strategy to transform Singapore into a knowledge-based society with solid capabilities in research and technology.

the research community (Wong & Kannan). Moreover, before issuing a grant, they connect with funding bodies and patterns overseas to benchmark best practices (Wong & Kannan). However, the ultimate fund allocation is set by the NRF and the RIEC under the directions of the Prime Minister (Wong & Kannan). Currently, there are two seats within the council allocated to people within the defense sector, the two people being Mr. Teo Chee Hean, Senior Minister, Coordinating Minister for National Security, and Special Advisor to NRF, and the Minister of Defense, Dr. Ng Eng Hen (Wong & Kannan).

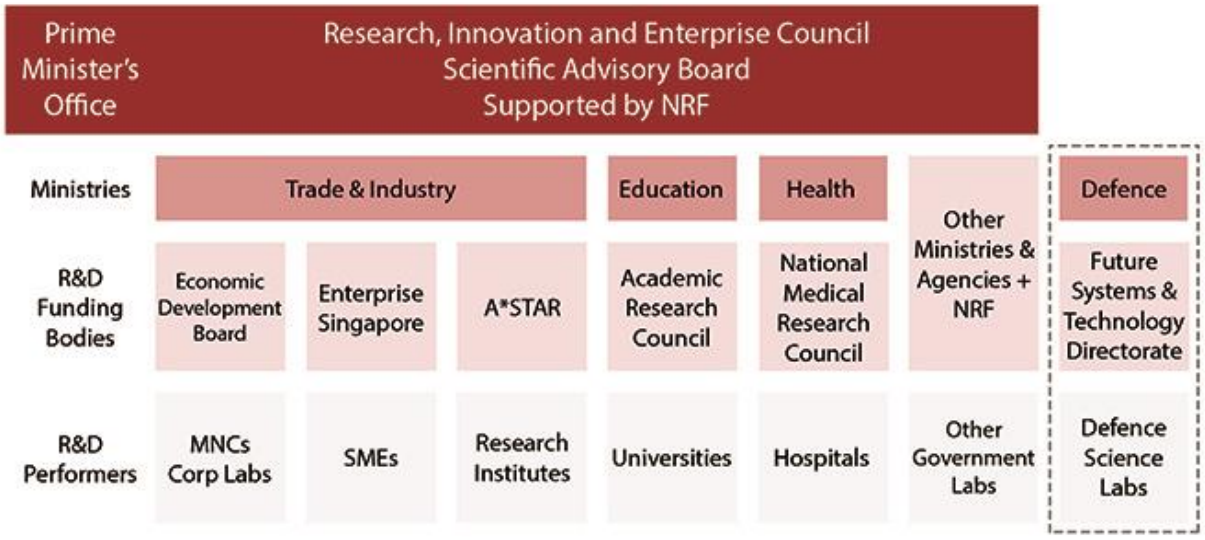


Figure 1: Ministries, R&D funding bodies and R&D performers (source: NRF)

billion in 2017 due to the increase in Public Expenditure on R&D (PUBERD) and Business Expenditure on R&D (BERD) (Ministry of Trade and Industry, 2019). In 2017, BERD accounted for 60% of the overall gross expenditure on R&D, an increase mainly supported by higher R&D spending by foreign SMEs enterprises and large foreign enterprises (*see figure 2: BERD by Firm Type, 2002 – 2017*) (Ministry of Trade and Industry, 2019). Singapore is aware that it cannot achieve self-sufficiency across all platforms and weapon systems. Therefore instead, it focuses on niche defense areas by leveraging its electronics and communication strengths while still achieving fundamental defense reliance (Andrew , 2013).

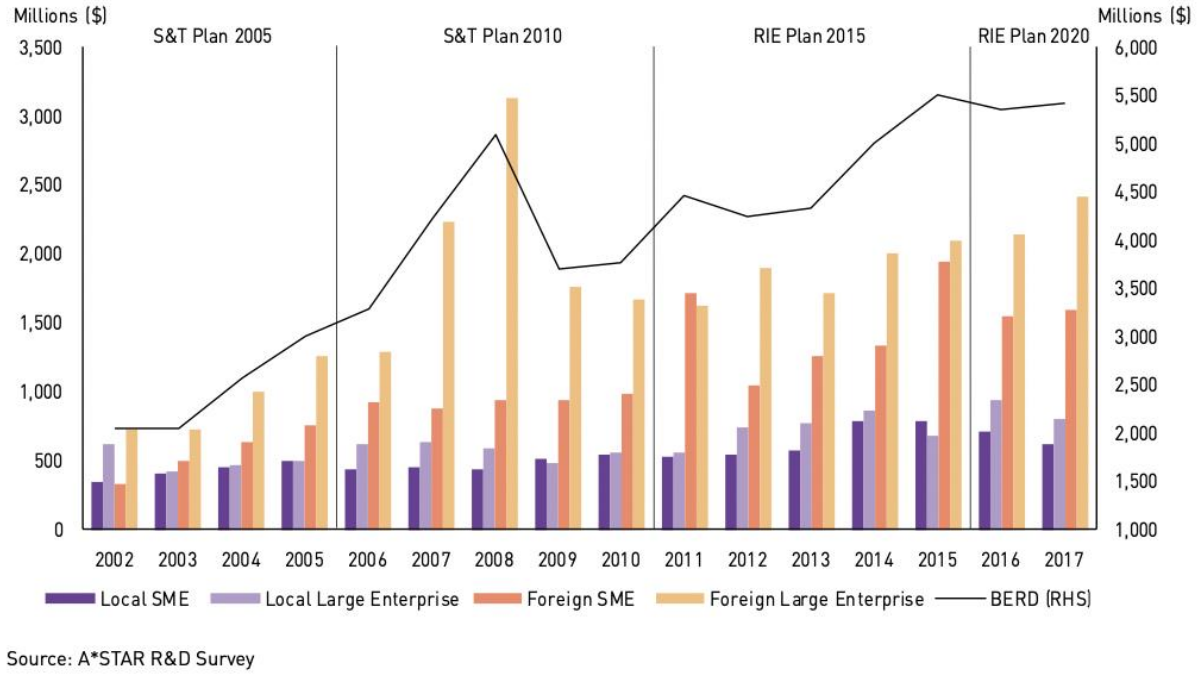
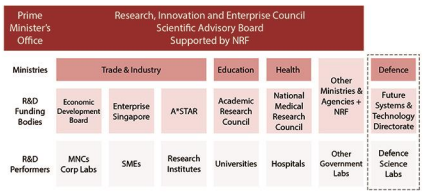


Figure 2: BERD by Firm Type, 2002 – 2017 (Ministry of Trade and Industry, 2019)



(ICD Research, 2021) According to the World Bank, Singapore is allocating 3.2% of its GDP towards military expenditure, including investing in new advanced technology for its armed forces (ICD Research, 2021). Since it is not efficient for Singapore to produce all types of technologies locally, and as a return for their investment in high-valued items, they require suppliers to sign a technology transfer agreement for all defense purchases allowing Singapore to maintain and customize equipment per their needs (ICD Research, 2021). Additionally, Singapore's Foreign Direct investment policy (FDI) allows investors to fully own and operate foreign defense entities with favorable tax laws and existing plans (ICD Research, 2021). The government primarily owns Singapore's defen (ICD Research, 2021).

Scope

Coming from little to no military platform, Singapore's objective was to reach self-sufficiency by covering its bases through the development of primary defense (Andrew , 2013). It achieved its aim

by setting realistic and limited outcomes that included the production of ammunition and small arms, the maintenance and repair of weapons systems, the building of patrol boats for the navy, and the refurbishment of military aircraft (Andrew , 2013). Three prominent defense companies dominated the field: the Chartered Industries of Singapore (CIS) – est. 1967, Sheng-Li Holding - est. 1974, and the Defense Technology Group - est. 1986. The three companies serviced three SAF divisions, the army, the navy, and the air force (Andrew , 2013).

The debates on military affairs transformation (RMA)[3] and the successful application and victories driven by this methodology intrigued Singapore (Andrew , 2013). Singapore adopted the RMA school of thought as it promises to overcome its strategic weaknesses, such as lack of strategic depth, heavy external reliance on trade and resources, and the lack of standing military manpower due to its small population (Andrew , 2013). In 2000, Singapore set its new ambition to achieve battlefield superiority by building Third Generation SAF based on specific technologies in precision strikes, advanced networks, and unmanned systems (Andrew , 2013).

During this time, the term "defense ecosystem" became popular, and it refers to the interlinked relationship between the SAF, R&D agencies, and the defense industry (Andrew , 2013). Recognizing and understanding this term pushed the Singaporean defense industry to evolve through better strategic management and integration within the defense industry (Andrew , 2013). Moreover, it directed the defense industry towards commercialization and diversification into non-military areas and commercial business activities that could potentially cross-subsidize the maintenance of facilities meant for military production and maintenance (Andrew , 2013). Singapore is encouraging public-private R&D partnerships and the establishment of technology transfer offices and enterprise incubators to cover the costs of R&D (ASEAN Member States).

4.1.3. Overview of National Research-Intensive Universities

An aspect of Singapore's success is its education system (K12 Academics). Singapore had to adopt a "survival-driven education" system to provide primary education for most of the population, prepare

[3] RMA Revolution in Military Affairs; the belief that modern militaries are on the cusp of a Revolution in Military Affairs (RMA), driven by recent advances in information technologies (IT), has long been an increasingly powerful and persuasive school of military thought

an adequate workforce for Singapore's industrialization program, and lower the unemployment rate (CIWIPO, 2016). Moreover, Singapore introduced a bilingual policy in schools to bring the new nation together, making English its official language (Tan & Pak , 2011). Economic prosperity and technological development pace drove Singapore to shift its focus from quantity to quality in education by introducing more diverse programs (*i.e., gifted education program*s) and streams (*i.e., Technical, Academic streams*) (K12 Academics). In 1997, the vision set by Prime Minister Goh Chok Tong, "Thinking Schools, Learning Nations," emphasized national education, creative thinking, collaborative learning, and ICT literacy (Mondeja, 2017).

Before 2000, research in Singapore was not prioritized, considered underdeveloped, and had few investments (Andersson, 2017). Today Singapore has three research institutions, including two top universities (*the National University of Singapore, or NUS, and NTU*). As a research institute, it has A*STAR, the Agency for Science, Technology, and Research. Funding is mainly granted by the National Research Foundation (NRF) (Andersson, 2017).

Nanyang Technological University (NTU)

NTU's roots can be traced back to 1955 with the establishment of Nanyang University - the only private university taught in the Chinese language during the British Colony offering courses in the arts, sciences, and commerce (AI-Youbi, Zahed, & Tierney, 2020). The idea of having a Chinese university was introduced by Tan Lark Sye, a Chinese philanthropist, businessman, and the chairman of the Singapore Hokkien Association (SHHK)[4] (AI-Youbi, Zahed, & Tierney, 2020). The university was founded on capital generated from crowdfunding and 500 acres of land donated by the Singapore Hokkien Association in the western Jurong area, south of the current Nanyang Technological University (NTU) main building (Government of Singapore).

National University of Singapore (NUS)

Student enrollments in the 1970s were dropping at Nanyang University as students favored English language schools due to job and pay prospects. This was evident as Chinese-educated graduates from

[4] is a cultural and educational foundation. It was established in 1840 to promote education and social welfare and to preserve the Chinese language and culture among Chinese Singaporeans and other Overseas Chinese groups in Southeast Asia.

the then-Nanyang University lost out to their English-educated peers from the then-Singapore University (Government of Singapore). The fear lies in the presentence of this pattern, as it will drive the university to close its doors permanently and create a significant shift in the social structure and wealth distribution (Government of Singapore). To avoid that, the Prime Minister of Singapore, Lee Kuan Yew, introduced a strategy to integrate, transform, and adopt the English language within five years (Government of Singapore). By then, an arrangement was introduced allowing students from Nanyang University to jointly study with students from the University of Singapore (Government of Singapore).

Singapore being a relatively young country on the rise, it is essential to build a solid economic, political, and educational infrastructure from the early years (Government of Singapore). Therefore, Prime Minister of Singapore Lee Kuan Yew invited British academic Frederick Dainton to discuss his views on the Singaporean higher education structure (Government of Singapore). He suggested merging Nanyang University and the University of Singapore (Government of Singapore). The government supported the idea, and the merger was confirmed (Government of Singapore). The act took effect in 1980, legally merging the University of Singapore and Nanyang University to form the National University of Singapore (NUS) (Government of Singapore).

Nanyang Technological Institute (NTI)

In 1981, Nanyang Technological Institute (NTI) was created in affiliation with the National University of Singapore to occupy and take over the Nanyang University campus (Toh, 2008). Starting with 582 students in 1981 and three major engineering disciplines (*civil and structure, electronics and electrical, mechanical and production*) to 6832 students in 1990, with the first two graduate students enrolling in 1986 (Toh, 2008).

In Singapore, universities are perceived as an essential tool for economic growth. Hence, manpower planning and higher education policy are delegated to Economic Development Board (EDB) (Toh, 2008). To respond to market demand, as per EDB, NTI introduced three more engineering disciplines, started a school of applied science, and fully integrated the School of Accountancy from the National University of Singapore into the NTI campus by 1987 (Toh, 2008). In 1990, the government announced the merger of the Institute of Education with the College of Physical

Education to form the National Institute of Education to be merged later with the National Institute of Technology and Nanyang Technological University (NTU) (Toh, 2008).

4.1.4.National University's Participation in Singapore's Defense Ecosystem

Joint or funded research centers for defense innovation

In Singapore, the research funding process has been coordinated and organized by the National Research Foundation since 1991[5] (National Research Foundation (NRF), 2021). Funding is not limited to having a very intensive research paper and implementing it and transitioning words into reality; only then can it have a significant impact (Andersson, 2017). Moreover, funding covers recruiting excellent people and managing collaborations and partnerships (Andersson, 2017). In a nutshell, research and innovation require concentrated efforts and a steady funding stream. Mr. Anderson[6], argues that there is no such thing as "too much funding" by comparing his experience in Singapore with his experience at European Science Foundation (Andersson, 2017).

Research Centers within Singapore are established by the government or its agencies or in collaboration with international universities and bodies. In this case, funding is shared between Singapore and its counterpart. For instance, if we look at NTU on a national level, NTU hosts two out of five research centers of excellence (RCEs)[7] With grants of USD 120M each, to be spent over the next 5 – 10 years provided by the government (Nanyang Technological University, 2020). The two centers are the Earth Observatory of Singapore (EOS) and the Singapore Center for Environmental Life Sciences Engineering (SCELSE) (Nanyang Technological University, 2020). On an international level, NTU is the lead local partner in seven out of ten national CREATE centers, alongside elite international universities[8] (Nanyang Technological University, 2020). Research is conducted within and across colleges/schools and RECs and is supported by nine universities level research institutes, ten corporate labs, 53 research centers under the colleges and schools (See Appendix A), and 24 joint

5 The National Research Foundation (NRF) is a Prime Minister's Office Department. Responsible for formulating 5-year plans and policies to grow Singapore's research capability, support economic growth, and meet Singapore's future national challenges.

6 Bertil Andersson, a Swedish college administrator, and academic who served as the third president of Nanyang Technological University

7 RCEs carry out world-class investigator-led research aligned with the long-term strategic interests of Singapore.

8 Campus for Research Excellence And Technological Enterprise (CREATE) is an international research campus and innovation hub. It aims to bring together researchers and academics from different disciplines and backgrounds to work together on cutting-edge research in areas of interest, leading to positive economic and societal outcomes for Singapore.

centers with external organizations (Nanyang Technological University, 2020). The initiative supported the creation of the Berkeley Education Alliance for Research in Singapore (BEARS), Nanomaterials for Energy and Water Management, and Singapore-MIT Alliance for Research and Technology (SMART), to say the least (Nanyang Technological University, 2020). Moreover, NTU built partnerships with international universities such as King's College London, Carnegie Mellon University, and Korea Advanced Institute of Science and Technology *(See Appendix B)* (Nanyang Technological University, 2020). (Nanyang Technological University, 2020)

Looking at the defense–university collaboration, NTU directly collaborates with MINDEF through their Temasek Laboratories established at NTU (TL@NTU) back in 2003 (NTU, 2022). This lab aims to conduct R&D programs that will accelerate technological breakthroughs in defense science and technology and facilitate conversation and knowledge transfer (NTU, 2022). The TL@NTU collaborates locally and internationally on multidisciplinary projects or selected topics (NTU, 2022). They have worked closely with the Massachusetts Institute of Technology (USA), Army Research Lab (USA), ONERA (France), Delft University of Technology (Netherlands), TU Darmstadt (Germany), and Kyushu Institute of Technology (Japan) at minimum (NTU, 2022). The lab partnered with colleges and research centers within NTU, such as the Satellite Research Centre (SaRC). Within the community, TL@NTU has partnered with DSO National Laboratories, Defense Science and Technology Agency, National University of Singapore, and ST engineering to translate research work into defense technologies application (NTU, 2022). NTU believes the collaboration will bring the Singaporean defense community to a greater height (NTU, 2022).

- ***Office of Research & Technology in Defense & Security (ORTDS)***

The Office of Research & Technology in Defense & Security (ORTDS) is an established office that comprises all defense-related centers and laboratories at NTU (Nanyang Technological University, 2021). It exists to bridge the communication gap between the defense sector and the education sector in specific research and development centers by identifying future critical research areas, capabilities, and educational opportunities (Nanyang Technological University, 2021). It acts as NTU's focal point with MINDEF easing direct dialogue, bridging the gap in discovery and application, raising funds, and ensuring effective resource allocation (Nanyang Technological

University, 2021). Moreover, attracting and building a talent pool of skilled young scientists and engineers, retaining them to ensure continuous growth in vital sectors, and assisting in integrating research (Nanyang Technological University, 2021).

Officially founded in 2015, with collaboration tracing back to 1988 with the first MOU signed between NTU (NTI then) and the Ministry of Defense (MINDEF) to co-find small-scale research projects in defense (*See Appendix E*) (Nanyang Technological University, 2021). ORTDS promotes collaboration through organizing workshops & discussions, research consultations, arranging visits & seminars, offering grant calls, and facilitating collaboration. Such collaborations facilitate discussion, networking, knowledge sharing, and brainstorming. Moreover, ORTDs work to manage talent, commercialization, and education (Nanyang Technological University, 2021).

RTDs manage the Electromagnetic Effects Lab (EMERL), the Satellite Research Centre (SIRC), Emerging Nanoscience Research Institute, and Temasek Laboratories at NTU (Nanyang Technological University, 2021). Utilizing its network and working closely with local and international industries, local and international universities and institutes and providing to its primary stakeholders such as the local defense and security agencies like the Cyber Security Agency, the Ministry of Home Affairs, and MINDEF (*See Appendix C*) (Nanyang Technological University, 2021).

Feeder programs for graduates

Graduate Feeder's program is offered to high achieving students to pursue higher education free of cost (MSC, 2021). In 1999, the Ministry of Defense (MINDEF) established the MINDEF Scholarship Center (MSC) (MSC, 2021). The center is tasked with assisting prospective scholars looking to attain the premier MINDEF/SAF[9] Scholarships (MSC, 2021). MSC hosts multiple events, tea sessions, career talks, and internship/attachment programs to exchange information about the range of scholarships available (MSC, 2021). The MSC offers six programs: The SAF Scholarship, PSC Scholarship (Engineering), SAF Engineering Scholarship, SAF Merit Scholarship, Defense Merit Scholarship, and the SAF Medicine Scholarship (MSC, 2021). All scholarship programs are open to

[9] SAF refers to the Singaporean Armed Forces.

Singaporeans and residents intending to take up citizenship of both genders (MSC, 2021). The program offers opportunities to study in Singapore or internationally with majors ranging from Philosophy, Politics & Economics to Law, Medicine & Engineering (MSC, 2021). The program assists graduates in developing professional skills and seeking personal growth as it grooms them for the highest level of command and management (MSC, 2021). The program offers a wide range of opportunities; for instance, Engineering scholarship programs consist of rotation amongst defense entities such as Defense Science and Technology Agency [DSTA] and DSO National Laboratories (MSC, 2021). Besides the full academic scholarship, the program offers a monthly salary, maintenance, and other allowances for books and clothing and return airfare. Furthermore, Students are offered an MSC officer for administrative support to focus on their studies and an opportunity to work and have a career in MINDEF/SAF agencies (MSC, 2021).

Within NTU, there are several scholarship programs supported by the defense industry, such as the Nanyang-DSO Graduate Program (NDGP), which is a joint scholarship By Temasek Lab @ NTU (TL@NTU) and DSO National Laboratories (NTU, 2022). The program was created to attract and foster Singaporeans to pursue defense and security R&D and, in due course, future leaders within the defense ecosystem (NTU, 2022). It is a full-time employment opportunity as a research assistant, with total paid tuition, a one-year overseas attachment program, and an internship at DSO National Lab or its partners (NTU, 2022). The program offers sufficient exposure to the defense ecosystem regionally and globally with a guaranteed career path. It is worth noting that the scholar will be working on pre-selected research and projects relevant to TL@NTU and DSO (NTU, 2022).

Support for defense innovation in universities' charters or strategic plans?

Since its founding, the Singaporean Government has set and implemented the comprehensive defense concept/strategy with the slogan “Together We Keep Singapore Strong” (MINDEF, 2022). The strategy calls for the responsibility of every Singaporean to defend the country in both military and non-military spheres (MINDEF, 2022). Total Defense comprises six pillars, Psychological Defense, Social Defense, Economic Defense, Civil Defense, Military Defense, and Digital Defense which was added in 2022 (MINDEF, 2022). The total defense has its day and is celebrated on February the 15th every year (MINDEF, 2022).

Figure 3: Total Defense Icons (MINDEF, 2022)

Following the introduction of the digital defense pillar, the Singaporean government has allocated $1 billion for the next three years to boost cyber and data security capabilities as per Minister Heng Swee Keat, the Finance Minister of Singapore, speech in 2020 (Parameswaran, 2020). In addition to proposing a USD 12 billion defense budget for 2022, an increase of 6.5 percent over the allocation in 2021 (Grevatt, 2022). Moreover, the Singaporean Armed Forced set up a new wing of its armed forces dedicated to digital security called "the Digital and Intelligence Service (DIS)" as part of the "SAF 2040" strategy to strengthen the defense against threats in the digital domain (MINDEF, 2022). (Grevatt , 2022)

NTU – Defense Support

NTU has released its “NTU 2025” strategy, which focuses on four pillars: Research, Education, Innovation, and Community (NTU, 2022). The strategy includes eight key initiatives: strengthening interdisciplinary, transforming innovation, and accelerating impact (NTU, 2022). Three main enablers drive all the initiatives: Financial, Talent, and Technology, and push for further industry-university partnerships with high societal influence (NTU, 2022).

Moreover, the strategy highlighted the efforts NTU will install to support the Government's national R&D priorities set by the RIEC and the RIE 2025 plan (NTU, 2022). Since the MINDEF chairs two

seats in the RIEC, efforts by NTU will include any defense-related projects in the pipeline (NTU, 2022). Furthermore, NTU highlighted its intention to influence the public policy and the public sector initiatives with its research findings and education expertise and through intensifying community engagements and collaboration with public agencies and industry partners (NTU, 2022).

4.1.5.Summary of Singapore Case

Singapore had low to few natural resources with limited agricultural access, a 10% unemployment rate, and a significant portion of its population deprived of education and healthcare access. Not only that, but interests from neighboring countries in also proclaiming Singaporean lands and post conflicts risks posed a threat to its existence. For that reason, Singapore proposed a military-political strategy and an economic transformation strategy. The military-political strategy consisted of introducing compulsory military service, signing peace treaties with neighboring countries and influential global players, joining the UN and commonwealth of the nation, and co-founding the Association of Southeast Asia Nations (ASEAN). All these initiatives protect its sovereignty and prolong peace together with promoting socio-economic-cultural & political advancement & cooperation. Singapore had to have a stable economy to back its military-political efforts and strategy, hence, the introduction of the economic transformation strategy. The government borrowed loans from the World Bank and utilized them to build a resilient infrastructure (i.e., water interconnection, sewage, and power systems), then invested it in human capital and the service sector (i.e., environmental management programs, development of the national university). During that time, the government had to compete with low-wage countries and copy and amend some of their economic policies to float. Gradually, the government was able to repay the loan to the World Bank and transform into a significant manufacturing and economic hub with completer economic freedom provided by low taxes, few capital restrictions, and liberal immigration policies. The country specializes in electronics, precision engineering, information & communication, and finance and industries.

Regarding our initial topic of interest, we looked at the character of Singapore's defense ecosystem and the State–Defense–University level of association and influence. Starting with

understanding Singapore's defense ecosystem by considering its maturity, scope, and structure and we concluded the following points accordingly:

- The defense Ecosystem includes all public and private firms that are commercially involved in the research and development, engineering, design, production, delivery, and maintenance of military weapon systems, subsystems, and components or parts according to the military requirements (CISA). All firms perform under contract to the Singaporean Department of Defense and provide products and services to the Department of Defense and government-owned/government-operated facilities essential to mobilize, deploy and sustain military operations (CISA).
- **Maturity:** Singapore's defense industry can be traced back to 1965, after its independence from the Malaysian Federation. At that period, Singapore had no diplomatic ties, surrounded by two countries in conflict resulting in high tension and political instability. The research was not prioritized – little to no investments were allocated. Due to the reasons above, Singapore understood the importance of building a resilient defense ecosystem and has ranked it as a high priority while heavily investing in R&D centers in parallel.
- **Structure:** Funding is highly structured and organized due to limited resources. Since 1991, all funding (from local and international agencies) has gone through the National Research Foundation (NRF) under the prime minister's office. The NRF oversees the Research Innovation Enterprise Council (RIEC), which drafts the Research Innovation Enterprise Plan (RIE) every five years. The council is headed by ministries, funding bodies, R&D performers, and beneficiaries. It is worth mentioning that the two chairs in the RIEC are allocated to representatives from the defense and security industry. The plan assigns areas of development for the next five years and designates a budget accordingly. In 2017, 36.7% of R&D spending was from local enterprises, while %63.26 was from international players. Singapore is aware that it cannot reach self-sufficing in all defense platforms. Therefore, the government is implementing different market entry strategies in Procurement, FDI Policy, and others to overcome this hurdle. The first strategy, the procurement strategy, pushes suppliers to sign a knowledge transfer agreement which helps the government repair and maintain the equipment and customize it per their needs. The FDI

policy allows defense companies to operate within Singapore and be wholly owned by foreigners, and this is pushed by tax incentives and an easy exit plan. Moreover, the government has introduced an online portal for suppliers to register and get a license to start trading and bidding with the government, as well as lease-to-own arrangements, which translate to leasing the products with multiple down payments until they fully own them, which reduces capital investment and allow Singapore to have early access to technology while reducing commission.

- **Scope:** Singapore wanted to overcome its strategic weakness resulting from a lack of strategic depth, heavy reliance on trade and resources, and lack of standing military power due to its low population. Singapore addressed its concerns via three defense development cycles feeding into its ambitions. In its early stages, Singapore developed primary defense intending to produce ammunition maintenance, repair, and build patrol boats. Then, Singapore set its goal to achieve battlefield superiority by building the 3rd generation of Singaporean Armed Forces (SAF) furnished with specific technology in precision strikes, advanced networks, and unmanned systems. At last, Singapore picked on the trending term "Defense Ecosystem," which pushes for the Defense – R&D integration resulting in commercialization and diversification into non-military areas & commercial business activities.

We then looked at the State – Defense – University level of association and influence by examining joint/funded research centers for defense innovation, feeder programs for graduates, and support for the defense innovation within the university charter. We have concluded the following points:

- **Joint/Funded Research Centers for Defense Innovation:** For the reasons mentioned earlier, funding is organized and structured, making research centers established by the government or their counterparts. Research centers established with the government's counterparts are considered joint research centers, and funds are equally shared. By viewing NTU, since it is our case study, we have categorized R&D centers into two categories: multipurpose R&D centers and defense R&D centers. Multipurpose R&D centers can then be sub-categorized into national and international centers. National centers are 100% government-owned, funded, and operated.

Regarding NTU, the university was granted two out of five Research Centers of Excellence (RCE) programs with endowments of $120M for each center from the government. Meanwhile, international centers are centers that are either operated jointly/with international universities and partners. NTU has multiple joint centers like Berkley Education of Alliance for Research, Singapore MIT Alliance for Research and Technology, King's College London, and Carnegie Mellon University. Likewise, Defense R&D centers are hubs for university–defense collaboration. NTU established the Office of Research & Technology in Defense & Security (ORTDS) with MINDEF in 2015 to overseas all defense-related centers and labs, bridge the communication gap between defense–education sectors, open direct dialogue, and lobby for funds. Additionally, it has established the Temasek Lab at NTU (TL@NTU), a joint program with the defense community to conduct research and development programs to accelerate technology breakthroughs in defense science and technology, facilitate conversation, and collaborate with local and international parties and other colleges within NTU.

- **Feeder Programs for Graduates:** Offered to high achieving students to pursue higher education at low cost. In 1999 MINDEF scholarship center was established to assist prospective scholars in attaining the MINDEF/SAF scholarship. Six scholarship programs are open to Singaporeans and residents intending to take up the citizenship with opportunities to study in local universities or internationally. Scholarships allow graduates to rotate between labs and entities to grasp what is waiting ahead. Scholarships are generally marketed through multiple events, workshops, career fairs, and talks and come with several incentives. NTU provides a scholarship known as the "Nanyang – DSO Graduate Program" it is a defense scholarship provided by TL@NTU alongside DSO national labs. The scholarship allows graduates to pursue higher education while taking up the role of a full-time research assistant. The program offers a full-tuition with a chance of a one-year overseas attachment program and an internship at DSO labs or its partners. It exposes graduates to the defense ecosystem and leading players while paving their career paths. It is worth mentioning that graduates will be confined to limited topics relevant to DSO needs, meaning that all research projects are pre-selected by the scholarship provider.

- **Support For the Defense Innovation Within University Charter:** NTU – Defense collaboration can be traced back to the 1st signed MOU in 1988, indicating that cooperation talks were established sometime before that. During that time, Singapore was going through a transition period where the presidency by parliament was replaced by the direct presidency via elections. Nonetheless, Singapore kept its "Total defense strategy," which installed the idea of defending Singapore in every sphere from a very young age. The strategy is based on six pillars, the sixth being is "Digital Defense," and was introduced in 2020 with a $1B budget to expand it. The new piler was introduced after the 2018 attack on its biggest healthcare group leading to a data breach. Following this announcement, and on a sectoral level, the defense sector has introduced the SAF2040 strategy with an initiative to create a new wing dedicated to digital security and intelligence called "The Digital & Intelligence Service (DIS)". Consequently, NTU has introduced the "NTU2025" strategy focusing on four pillars, research, innovation, education, and community, and eight initiatives to support it. The strategy pushes for industry-university synergy (collaborating with influence), supports government R&D priorities set by RIEC and the RIE plan, and declares the desire for NTU to influence public policy and sector initiatives by research funding and education expertise, intensifying community engagements, and finally collaboration with public agencies and industry partners.

4.2. Case Two: South Korea

4.2.1. Background of South Korea's politics and economy

South Korea has been on a rough path to gaining its independence. Since the beginning of the century, the Korean Peninsula has been under the invasion of the Chinese, Mongols, Japanese, Soviets, Americans, neo-liberals, and the communists (South Korean Government).

Before its independence, the peninsula was under Japanese rule (*during 1910 – to 1945*) (South Korean Government). The Empire of Japan annexed the Korean Empire (South Korean Government). Koreans were forced to adopt Japanese names and were prohibited from speaking their language (South Korean Government). Many Koreans were forced to work in unsafe conditions in Japan or pushed to aid in the undergoing pacific war Japan was undertaking (South Korean Government).

Women and girls were trafficked, and the Japanese depilated Korea's resources (Morgan, 2018). On August 15, 1945, after two atomic bombs (Nagasaki and Hiroshima) and almost the end of World War II, Japan surrendered, announcing the end of its rule over Korea (Clippinger, 1964).

The Korean Peninsula was not exempted from the USA's and the USSR's expanding influence. The departure of Japan unwrapped a new playing field for the big giants (Robinson, 2007). Despite the UN efforts to bring the nations together under fair elections, the USSR and the USA divided the peninsula along the 38th parallel[10] In 1945, dividing it into north and south regions and determining each power's sphere of influence[11] (Robinson, 2007). The USSR appointed Kim Il-sung (*communist*) in the north, and the USA backed Syngman Rhee (*capitalist*) in the south. Both leaders had hopes of unification under his ideology (Robinson, 2007).

In the hopes of unification, the General Assembly of the United Nations recognized the Republic of Korea (*the southern part of Korea under President Syngman Rhee*) as the sole legal government of Korea in 1948, leading to the withdrawal of USSR troops within the same year and the USA the year after (Robinson, 2007). Refusing the new borders, North Korea invaded South Korea, breaching the 38th parallel ending all hopes of peaceful reunification in 1950 and starting the notorious proxy war known as the "Korean war" (Larson, 1989). The Korean war was a proxy war, one of its first kind, fought on behalf of the USA to **"Contain the Spread of Communism"** and the USSR's communist ideology on foreign soil (Larson, 1989). An intense war broke out between both parties, and North Korea was backed by communist China and the South by the UN coalition (Larson, 1989). In 1953, the Korean Armistice Agreement was signed, ensuring a complete ceasefire and creating a demilitarized zone until a peaceful settlement was achieved (United Nations, 1953). Neither side pushed for any further settlements or agreements as both regions were going through political shifts of their own. North Korea a communist-led by the dictatorship. While South Korea battelled through five failed leadership attempts, settling down as a prosperous, democratic state in 1987 under Roh Tae-woo's presidency.

10 38th parallel, a popular name given to latitude 38° N that in East Asia roughly demarcates North Korea and South Korea. US military planners chose the line at the Potsdam Conference (July 1945) near the end of World War II as an army boundary north of the USSR.

11 is a spatial region or concept division over which a state or organization has a level of cultural, economic, military, or political exclusivity.

In 1953, and after the Korean War and the establishment of a military zone between the north and the south, the southern people swore off communism. After establishing the 38th parallel, the Korean peninsula was divided into the Democratic People's Republic of Korea (DPRK) in the north and the Republic of Korea (ROK) in the south (Seth, 2017). The economic situation of both regions was horrendous, with the north being slightly better. The division gave DPRK most of the mining, and more than 80% of the electric power generation, while the ROK inherited most of the productive agricultural areas (Seth, 2017). Yet, that was not sufficient to push ROK out of poverty as it faced other challenges, including refugees' influx from the north, loss of primary agriculture importer (*being japan*), and the repatriation of a lot of skilled Japanese workers back to Japan all of this compounded caused a significant economic burden on ROK (Seth, 2017)

South Korea was poor, underdeveloped, and living off American aid (Graham, 2003). The US provided South Korea with financial aid, hoping it would boost their economy, yet for many reasons, it was sufficient to feed the starving population and maintain military operation (Graham, 2003). The American aid accounted for 80% of all ROK revenue (Seth, 2017). One of the reasons the aid failed in supporting the economy as corruption and favoritism, pushing into creating a new class of wealthy people as money was going to private use and users. This participated in creating Chaebol[12] (*i.e., Samsung, LG, Hyundai, and SK Group*) that will, later on, be one of Korea's leading economic and political players (Graham, 2003). Another reason was the import substitution policy[13]Injecting money or directing cash flow to specific people only creates a class of wealthy entrepreneurs interested in keeping or maintaining the failed policies in place to support their interest (Graham, 2003). Likewise, an introduction to Protectionism economic policy[14] It was introduced and backed by the US, limiting exporting Korean products to the US (Graham, 2003). With corruption and favoritism in giving out imports licenses, the policy has caused a considerable deficit between imports and exports, hindering economic growth (Seth, 2017).

12, A sizeable industrial conglomerate that is run and controlled by a person or family in South Korea.

13 Import substitution industrialization (ISI) is a trade and economic policy that advocates replacing imports with domestic production.

14 Protectionism is the economic policy of restricting imports from other countries through methods such as tariffs on imported goods, import quotas, and various other government regulations.

Internal changes were taking place, such as land reform, where limitations on land sizes were set, giving a chance for most people to own land and get rid of tenancy (Seth, 2017). This meant more money was allocated for commerce, industry, and education (Seth, 2017). Education was spreading for the first time in ages (Seth, 2017). The number of student enrollment from primary school up to high school tremendously grew (Seth, 2017). In 1960, 96% of all primary school children attended school (Seth, 2017). Moreover, adult literacy programs were introduced to ensure that primary education is provided to the remaining population (Seth, 2017). These reforms gave ROK the best-educated workforce in any country with a comparable income level (Seth, 2017).

President Park Chung Hee was the longest-serving president in the chair, serving five consecutive terms until his assassination in 1979 under a military regime (Seth, 2017). Despite his lack of knowledge of the economy, President Park had one thing in mind: abolish poverty and eliminate foreign dependence (Seth, 2017). Nationalism was his strongest motivation for economic reform (Seth, 2017). He detained and fined corrupt business leaders, including the wealthiest man in ROK at that time, then utilized their knowledge in conducting business and entrepreneurship to build and develop the economy and appointed them to the newly established Promotional Committee for Economic Reconstruction to lead the change (Seth, 2017). Likewise, established the Economic Planning Board (EPB) to oversee the newly drafted five years-development plans, establish complete control of state credit by nationalizing all banks, redirect the import substitution policy to export-oriented industrial development, and provide low-interest loans for startups and business owners to kickstart their businesses (Seth, 2017). The plan generated 8.9% economic growth and increased the overall country's exports to 29% (Seth, 2017). This drastic growth pushed for the development of another five-year plan, this time focusing on foreign direct investments and improving infrastructure (Seth, 2017). The US was pulling back on its financial aid and military support to ROK as the economy grew, meaning more economic growth and less aid from the US (Seth, 2017). This pushed ROK to develop new strategies to upsell its technical capabilities and contract. For instance, ROK supported the US in the Vietnam war with 300,000 troops; in exchange, South Korean firms were to be given lucrative contracts to supply goods and services to the South Vietnamese, American, and allied military forces (Seth, 2017). After the Vietnam war, the US-China deal, and Nixon's emphasis

on the reduction of US military forces in the ROK, the government realized the importance of being a self-reliant nation shifting their economic strategy toward the development of heavy and chemical industries inaugurating the HCI (heavy and chemical industry) phase of South Korea's economic development.

Talent is crucial for any developing country, especially to cope with its shifting economic strategy. Therefore, acquiring the right talent for ROK meant providing diverse talent programs, various courses, and study options (Seth, 2017). The government established several centers like the Korean Institute of Science and Technology (KIST), in 1966, as an asset in transferring technical knowledge to business enterprises (Seth, 2017). It also promoted technical education by expanding the number of vocational secondary schools and two-year technical colleges and encouraged students to study abroad (Seth, 2017). To avoid the spread of corruption and professionalize the state's bureaucracy, the government built a highly competitive civil service examination system on hiring people by merit (Seth, 2017).

4.2.2.Maturity, Structure, and Scope of South Korea’s Defense Industrial Sector

Maturity

South Korea signed a mutual defense treaty with the US in 1953, which provided it with armory from the States mainly under the Foreign Military Sales Program and Military Assistance program between 1960 and 1986 (Moon, 1991). The program fulfilled Korea's military needs via international imports, yet it crippled it from developing its defense industry (Moon, 1991). During the time, South Korea relied utterly on imports, primarily from the US, to satisfy its military needs, from simple ammunition to aircraft, and on the presence of US troops on its grounds to deter North Korea's aggression (Moon, 1991). However, that did not last for long, and the US withdrew its troops as part of the Nixon Doctrine from South Korea despite the rise of the aggression perceived by North Korea and abandoned Vietnam in 1975. Doubts have arisen regarding the US security commitment to pushing South Korea to realize the importance of self-sufficiency and embark on a race to independence in the 1970s (Moon, 1991).

The journey took multiple phases to reach its current stage, the first phase being the Military Import Substitution (MIS). In this phase, massive investment took place to develop necessary infrastructural and institutional settings for the defense industry (Moon, 1991). The defense industry built its production platform through reverse engineering imported arms guaranteeing South Korea's primary weapons need were met (Moon, 1991). Once its basic needs were met, the country shifted its production to include advanced weapons systems such as naval vessels, missiles, tanks, and communications equipment (Moon, 1991). In this stage, the government started relying on its R&D centers to direct its products and finally reached a plateau and pushed towards export promotion (Moon, 1991).

Structure

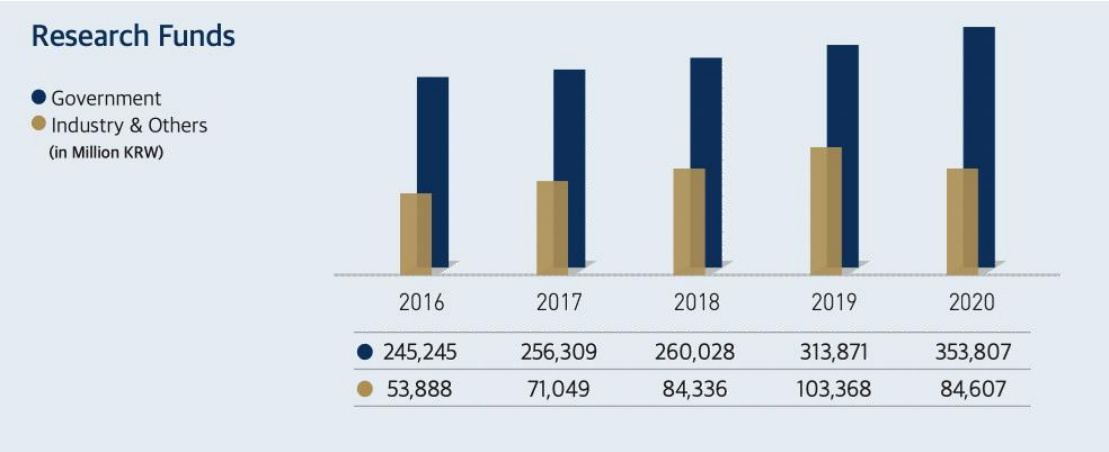
The Defense community in South Korea consists of government entities such as the Ministry of National Defense, Defense Acquisition Program Administration (DAPA), ROK Chief Of Staff (each force), and the Agency Of Defense Development, as well as research entities, universities, and enterprises. All were collaborating on different research projects and areas of development (i.e., AI branch, Sensor's branch, Cyber Branch) (KRIT, 2022).

The Korean government has relied on the private sector, including contractors, mid-sized subcontractors, and Chaebol.[15] (i.e., Samsung, LG, Hyundai, and SK Group) for defense industrialization since its establishment. For businesses, the substantial advance payment, lack of competition, and guaranteed procurements are all important reasons to take on defense contracts. On the other hand, the government benefits by offsetting potential losses from military-industrial production.

In 2020, %4.81 of the country's GDP was allocated to R&D investments, equivalent to $75.4 billion, and %57.8 is accredited by corporate/large enterprises (approximately $43.61 billion) (UNESCO, 2020). Referring to the defense sector, %2.5 of the country's GDP (roughly $45.7 billion) was allocated to the Defense sector, with %6.32 (about $2.89 billion) assigned to defense R&D projects

15 A large industrial conglomerate is run and controlled by a person or family in South Korea.

(KRIT, 2022). Looking at KAIST, in 2020, %23.9 of R&D projects are sponsored by industry players, while %76 are by the government (Research Funds 2016 - 2020 (source: KAIST).



Research Funds 2016 - 2020 (source: KAIST)

There is a system followed in South Korea for resource and fund allocation for R&D centers (*including KAIST*). ROK established the Korea Council of R&D Funding Agencies (CORFA) in 1997 to provide professional research management services (CORFA, 2021). Those services include management of national R&D projects, evaluation of milestones, and help on building cooperation between organizations in exchanging of information, as well as planning and other administrative services (CORFA, 2021). CORFA includes many governmental organizations, including the Defence Agency for Technology and Quality, overlooked by the Defense Acquisition Program Administration (CORFA, 2021). Each organization contributes according to its scope of work; for an instant, the Defence Agency for Technology and Quality works on promoting information and telecommunication technologies and industries by supporting R&D, its role is to work on ICT Policy Research and Analysis, developing strategy and planning while evaluating R&D funding, performance, technology commercialization, and develop infrastructure and human resources needed to ensure the continuation of its operation (CORFA, 2021)).

Scope

As noted previously, the defense industrial sector within South Korea took several forms starting with the implementation of the military import substitution policy that pushes for the “Buy Korean” consumer behavior (Moon, 1991). After cycles of heavy investments and policy reforms, Korea was

able to secure its basic weaponry systems and ammunition (Moon, 1991). Following this success, Korea switched its production processes to include heavy/advanced weaponry systems via relying on its R&D centers to direct their products and finally reaching a plateau and pushing towards export promotion (Moon, 1991). Today, South Korea is the sixth-largest arms exporter in the world, with revenues ranging up to $827m, yet, in April of this year, the Defense Acquisition Program Administration (DAPA)[16] The Ministry of Defense enacted new legislation, "The new Defense Science and Technology Innovation Promotion Act," to accelerate the advancement of Korea's national capability in undertaking military-technology R&D (Grevatt , 2021). This law aims to foster innovative competition and create an open space for the defense R&D system by increasing private–government collaboration, reorganizing the defense R&D within ROK, prioritizing fourth industrial revolution technologies, and managing a business and governmental associations (Grevatt , 2021). Furthermore, the act proposed a new funding plan for 2021 – 2025, outlining the total defense funding of USD 235 billion, with USD 153 billion allocated for operating expenses and USD 79 billion for military modernization, including procurement and R&D (Grevatt , 2021). In 2021 the Ministry of National defense set the defense budget of USD 48 billion for different areas on investments related to security and weaponry advancement, including defense R&D (Grevatt , 2021). Following that announcement, the DAPA announced plans to allocate USD 3.9 billion of its budget to defense R&D alone (Grevatt , 2021). Later that year, ROK also announced its goal to become a global space & military power with the help of the private sector to deter growing aggression from North Korea (Onchi, 2021). It is worth mentioning that %10 of government spending is designated for the defense sector. Still, the government is the fourth largest arms importer in the world, as of 2020, with a spending of USD 1.31 billion (pieter, alexandra, & siemon, 2021).

16 An executive branch of the South Korean government was established on January 1, 2006, under the Ministry of National Defense to administer improvement projects of defense capability, procuring munitions, and fostering defense industries.

4.2.3.Overview of National Research-Intensive Universities in South Korea

South Korea has several advanced universities that conduct high-end research across various scientific and engineering domains. KIST was established in the 1960s with the help of American advisors to facilitate the growing need for researchers in the fields of science and technology, focusing on material science, electronics, chemical engineering, and mechanical engineering (Park , 2011). KIST was the first R&D institute funded by the government. The university failed to attract further researchers nor grow its own despite its humble contributions to promoting interest in research among businesses (Park , 2011). One of the main reasons behind this was its inability to teach, and the institute was not built as a teaching center (Park , 2011). Therefore, the need for highly qualified scientists and engineers equipped with theoretical and practical expertise persisted, thus establishing the Korean Advanced Institute of Science (KAIS) in 1971 (Park , 2011). KAIS was established with a loan of USD 6 million provided by the United States Agency for International Development (USAID) alongside human capital to assist the shift of ROK from a light-to-heavy industry (KAIST). The success of the ROK economic shift depended on the availability of strong, talented Koreans specializing in science and engineering fields (KAIST). The lack of foundation made it difficult for the university to kickstart its programs as required (KAIST). Therefore, USAID reached out to Frederick E. Terman.[17] To draft the blueprints with the help of a group of scientists, to be called later the "Terman Report" (KAIST). KAIS embarked on full-fledged preparations for its establishment, finally accepting its first batch of students in 1973 (KAIST). Its practicality is significantly differentiated between KAIS and other universities in Korea, like Seoul National University. It stressed the importance of lab work, problem-solving skills, and experience rather than theoretical knowledge

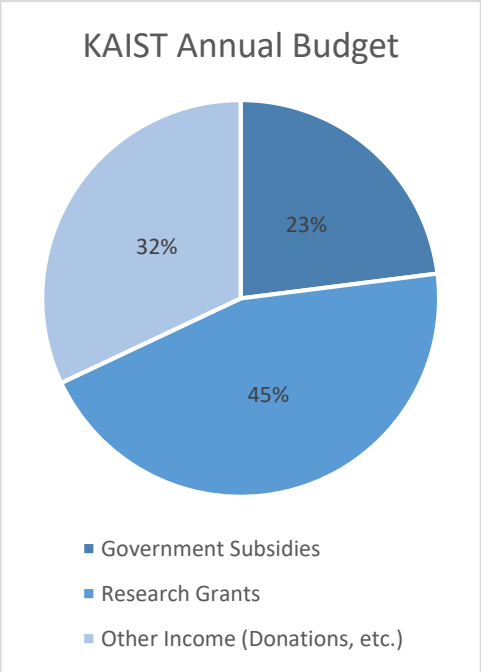


Figure 4: KAIST Annual Budget (Source: KAIST)

[17] "Father of the Silicon Valley," he created an industrial-academic convergence complex at Stanford University to highlight the importance of collaborative research between industries and universities.

alone (Park , 2011). In 1981, the government merged KAIS and KIST to form the Korea Advanced Institute of Science and Technology (KAIST). However, due to core differences in their research philosophy, the two entities had to split in 1989 (Park , 2011). KIST became an independent organization operating in Seoul. At the same time, KAIST maintained its new name and moved its operation to Daejeon (*referred to as the new science city back then*), around 140 kilometers south of Seoul (Park , 2011). This allowed KAIST to expand its operation, build more laboratories, host further research, and attract more conglomerates to the area (Park , 2011). KAIST's contributions to the Korean economy were of value; for instance, the surge in the development of Korea's semiconductor, automobile, and chemical industries between the 1980s – the 1990s can be attributed to KAIST graduates and professors (Park , 2011). Nowadays, KAIST is comprised of seven schools, thirteen graduate schools, and twenty-seven divisions, all under-five colleges, including the College of Natural Sciences, College of Engineering, College of Business, College of Life Sciences and Biology, College of Liberal Arts, and Convergence Science (KAIST, 2021). Currently hosting more than 10K students, third of them are enrolled in Ph.D. or Joint MS/Ph.D. programs and retain more the 60k alumni (KAIST, 2021). International presence is low, equivalent to 1000 members, less than 9% of the entire university population *faculty and Students*) (KAIST, 2021). Notably, 85% of the undergraduate courses are offered in English, a feature that can be utilized to attract more international students and faculty members (KAIST, 2021). Despite that, KAIST collected an international high ranking on several world indicators. QS ranked KAIST 39th on its World University Rankings 2020, 11th on Thomason Reuters World Most Innovative Universities 2018, and 4th on Nature Index Top Young Universities in the World 2019 (KAIST, 2021).

Funding in KAIST is around roughly USD 866 million, comprised mainly of government subsidies, research grants, and donations (*see Figure 1: KAIST Annual Budget*) (KAIST, 2021). This funding allows KAIST to provide scholarships and accommodation for students at a very affordable price (KAIST, 2021). Besides the institutes, KAIST has its own research centers, and collectively, with the institutes, they harbor more than 140 research centers that are investigating information technology, nanotechnology, biotechnology, space technology, environmental technology, cultural technology, and others (KAIST, 2021). These research projects are conducted by the government and other non-governmental parties (KAIST, 2021). The same can be said about research funds as it is sponsored by government and non-government partners (*i.e., industry, overseas, grants…*) (*see Figure 2: Sponsored Research Funds*) (KAIST, 2021)

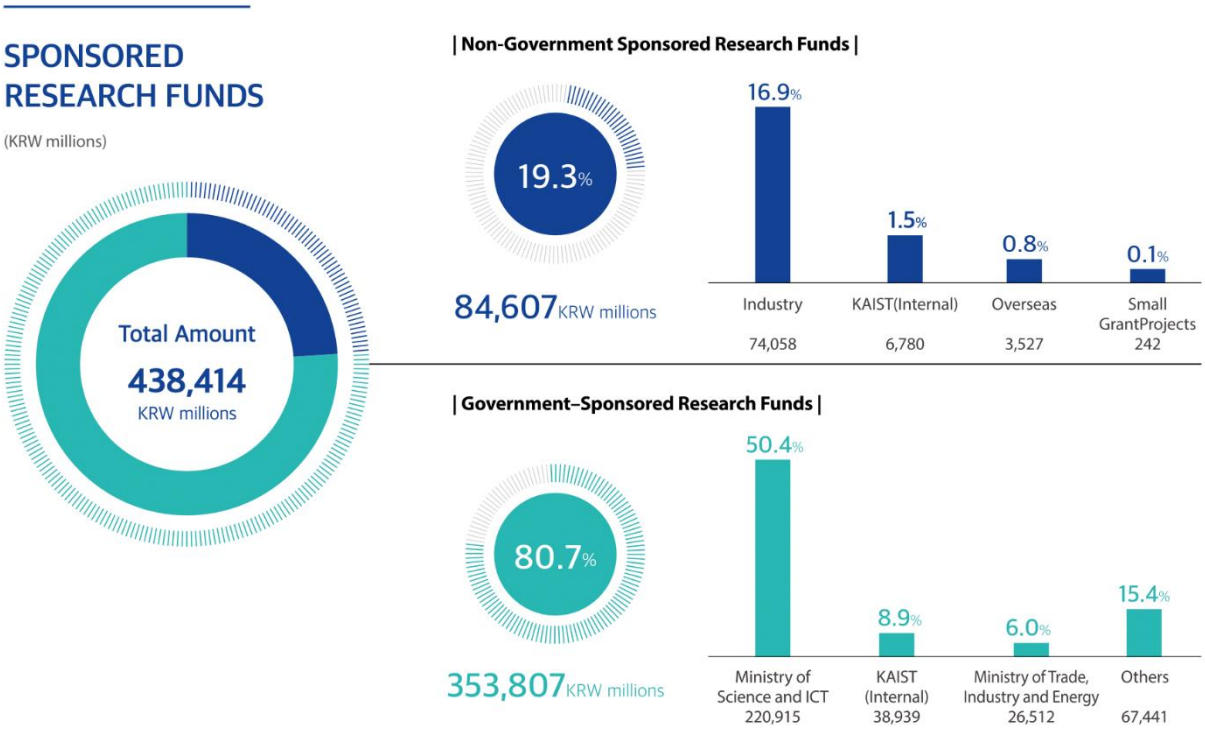


Figure 5: Sponsored Research Funds

4.2.4. National University's Participation in ROK's Defense Ecosystem

According to the Ministry of Defense of South Korea, the defense budget has increased from USD 38.3 billion to USD 48.3 billion in the last five years (MND, 2022). The budget is then distributed to the force improvement programs, the force maintenance, training and education, logistics supports,

and others (MND, 2022). It is worth mentioning that 30% of the budget is allocated to the Force Improvement program and 1.7% to Training and Education (MND, 2022).

Joint or funded research centers for defense innovation

Funding for Defense innovation in South Korea is offered by chaebols and the government itself (Jae-Ok & Moon, 2010). Since its establishment, South Korea has made business conglomerates part of its defense innovation ecosystem by assigning them to primary industrial sectors such as shipbuilding, stealing, electronics, and metallurgy (Jae-Ok & Moon, 2010). These entities were responsible for creating civil-military dual production (Jae-Ok & Moon, 2010). This initiative has been rewarding by reducing sunk costs, assuring a flexible production base, and facilitating technological innovation through the synergy of civil and military technologies (Jae-Ok & Moon, 2010). Defense R&D funding strategies have shifted throughout the years (Jae-Ok & Moon, 2010). Investments became more focused on technological development designed to secure source/core technologies, reinforcement of cooperation between the private sector and the military, and expansion of civilian participation in defense R&D (Jae-Ok & Moon, 2010). Budget allocation varies according to the type of research; research can be differentiated based on its complexity and is divided into the project (Jae-Ok & Moon, 2010). The first project is called projects for individual basic research (Jae-Ok & Moon, 2010). It is generally granted to universities and research institutes with the request to conduct primary research for essential items (Jae-Ok & Moon, 2010). Then comes projects for specialized research centers carried out on the essential items and university findings required to set the foundation for defense science and technology (Jae-Ok & Moon, 2010). Finally, projects for introducing new technologies through international cooperation are core technology projects that other countries refuse to transfer or sell to South Korea (Jae-Ok & Moon, 2010).

Going back to our case study, KAIST, there are roughly 200 research centers within KAIST across multiple colleges and disciplines. Some are set up exclusively by the university (i.e., KAIST Smart City Research Center), others with chaebols (i.e., LG Electronics - KAIST 6G Research Center), and a few with international conglomerates (i.e., Saudi Aramco-KAIST CO2 Management Center) (KAIST, 2022). Amongst the 200 centers, nine are allocated merely to defense-related research and are under the Institute for Security Convergence (KAIST, 2022). The majority of these

centers are established to fulfill specific market demands. Recently, following ROK 2021's deceleration of wanting to become a global space and military power, KAIST has established a partnership with Hanwha Group.[18] To develop several commercial projects and conduct space technology research (KoreaTechToday, 2021). The group pledged USD 8.8 million to the establishment of the center on KAIST and appointed the Vice President of Research, Lee Sang-Yup, in KAIST to supervise its creation (KoreaTechToday, 2021).

Feeder programs for graduates

There are multiple programs depending on the status of the recent joiner (ISCU, 2022). There is Military education, Human resources development, and Unit training, each serving a different goal, from candidate training to professional military education to group training to foster combat capabilities (ISCU, 2022). There are several scholarship programs for Koreans, and Foreign Nationals, North Korean defectors, talented Students, family & minority groups (i.e., Graduate Scholarship for Excellent Foreign Students (GSFS), Global Hope Scholarship, Korean War Memorial Foundation Scholarship), and Scholarship for Commissioned Education which Military Commissioned Education falls under (ISCU, 2022). The military commissioned education scholarship is provided to those pre-enrolled in the military and is granted during the student's military service, such as the Non-Commissioned Officers Candidates, Piolet Scholarship (ISCU, 2022). Besides military scholarship, multiple military academies and universities (such as KAIST) provide defense-related courses, such as the Military Academies, Reserve Officers' Training Corps, and Officer Candidate School (ISCU, 2022).

Case Study: The Institute of Security Convergence (ISC) – KAIST

ISC is an institute established by KAIST to increase cooperation between the private sector, government, and military by utilizing the KAIST's experience and competence in science and technology (*see figure 1: Major Project*) (ISCR, 2021). The institute consists of eight research groups focusing on cyber security & information, space systems and technology, defense technology, autonomous systems, energy system, materials, sensors, and quantum systems (*see figure 3: specific*

18 Hanwha Group is a significant business conglomerate in South Korea. They were founded in 1952 as Korea Explosives Co.

research areas) headed by the provost and the vice president of KAIST (ISCR, 2021). This establishment will help Korea to prepare for future threats and adapts to the social dynamics of war and warfare by overcoming its limitations in defense R&D, stepping away from traditional military technology and weaponry, and focusing instead on convergence technology[19] To enhance competitiveness and overall national security (ISCR, 2021).

ISC's mission is to train future-oriented security professionals, and its vision is to seek new challenges and commitment to national security (ISCR, 2021).

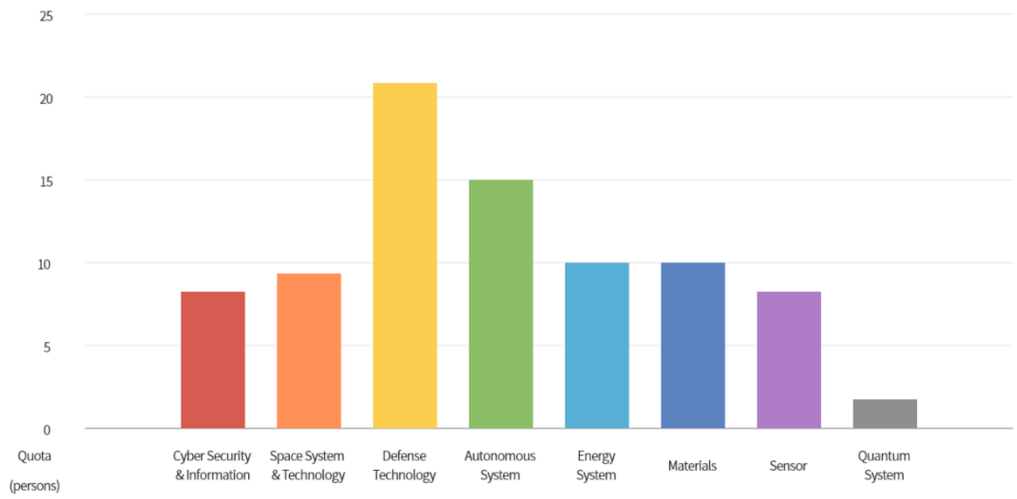


Figure 6: Specific Research Areas

The institute plan to conquer that by adopting research groups specialized in national security and defense to implement specific targeted research by the center while acquiring simple convergence technology and patents related to the field (ISCR, 2021). They were developing future security-oriented professionals through creating and altering training and education programs supporting all levels of educational backgrounds (ISCR, 2021). Enhance domestic and international cooperation by supporting the development of security-related technology, providing technical consulting for the Ministry of National Defense, creating international and domestic research hubs, and startup networking for patented technology development (ISCR, 2021).

[19] Technological convergence is a term that describes bringing previously unrelated technologies together, often in a single device.

The Institute for Security Convergence is headed by the Provost & Executive Vice President of KAIST. It oversees the Center of Security convergence Strategic Studies (the SC-Strategic Studies) (ISCR, 2021). The SC-Strategic Studies is responsible for guiding research, approving proposals, and deamination of information (ISCR, 2021). It hosts the Euiji Future Army Science & Technology Research Institute, which manages nine research centers like Theatre Defense Research Center, PoongSan-KAIST Future Technology Research Center, Center for Security Technology Research, and Center for Applied Research in Artificial Intelligence (ISCR, 2021).

The ISC signed an MOU in November 2011 with ROK Army to enhance military-academic cooperation (ISCR, 2021). The cooperation includes altered programs targeted at officers nominated by the military to obtain their master's or doctoral degree at KAIST under a fully paid scholarship by the army headquarters (ISCR, 2021). The military-academic scholarship recipient is classified as a general scholarship recipient, and it is handed to 10 – 20 selected officers each academic year, including army, navy, and air force officers (ISCR, 2021).

In the Fall of 2020, the ISC launched an ISC master & doctoral program for all interested students with 30 scholarships handed every academic year (24 from master's, six from doctoral programs) (ISCR, 2021). Both programs provide generous incentives to professors supervising the research (ISCR, 2021). Besides academic scholarships, ISC provides non-degree short-term educational programs for governmental agencies related to the security army, defense industry personnel, and so on (ISCR, 2021). The programs aim to prepare officers for dynamic changes in technology and warfare, provide a networking opportunity with and between experts in the field, and help officers understand core technology in security and defense (ISCR, 2021). Moreover, ISC continuously organizes seminars and forums, on-campus and online. Those talks are published then on their YouTube channel (ISCR, 2021). The seminars or forums are held and sponsored by KAIST with expert guest speakers (*officers, researchers, …).* The aim is to spread knowledge and discuss the latest findings and challenges to overcome (ISCR, 2021).

ISC Research centers work closely with domestic and international partners like the Ministry of National Defense, the agency for defense development, the ROK army, the ROK air force, the Hanwha systems, the Defense acquisition program administration, and more (ISCR, 2021).

Support for defense innovation in universities' charters or strategic plans?

Success in defense innovation can be seen in the ability of the government to provide basic weaponry in a short period, easy transition in cutting-edge defense industrial items, increase in defense exports, and constant industrial and technological upgrades (Jae-Ok & Moon, 2010). The success of defense innovation in South Korea is attributed to embeddedness in the commercial sector, linking spin-off and spin-on, ensuring competition, the “buy Korean” policy, and streamlining R&D investment and related activities (Jae-Ok & Moon, 2010). South Korea made it part of its strategy to cooperate with many prominent business conglomerates (chaebols) to engage in strategic industrial sectors (Jae-Ok & Moon, 2010). They were selected to engage in civil-military dual production (Jae-Ok & Moon, 2010). In 1970, 70% of all chaebol production capacity went to defense production and the other 30% to commercial production (Jae-Ok & Moon, 2010). As the demand for the military sector defense declined, the government adjusted the military-commercial production mix more flexibly (Jae-Ok & Moon, 2010). As part of its strategy and to encourage defense innovation, the government drafted several laws pushing for the support of civil-military dual-use technologies (Jae-Ok & Moon, 2010). The law required ministries of national defense, science and technology, industry, resources, energy, and information and telecommunications to form an association to undertake joint projects (Jae-Ok & Moon, 2010). USD 203.2 million was injected into 100 projects, and only 25 were successful (Jae-Ok & Moon, 2010). Despite that, between 1995 – 2008, the military transformed 102 defense technologies into 160 commercial firms (Jae-Ok & Moon, 2010). Moreover, the Korean government is constantly pushing for the “Buy Korean” policy, where domestic defense material is favorable over international acquisition (Jae-Ok & Moon, 2010). This policy has boosted the ROK defense industry, pushing the ratios from 54% & 46% domestic to foreign procurements in the 1970s to 77.5% to 22.5% in the 1990s. A trend is still kept today (Jae-Ok & Moon, 2010).

ROK has drafted the "Defense vision 2050" (Kim, 2021). The vision seeks to augment operational capabilities with artificial intelligence (AI) and combat robots (Kim, 2021). The "digital new deal" initiative was carried out as part of the vision to promote business development and job security through digital technologies (Kim, 2021). This deal has resulted in a new partnership between South Korea's Ministry of National Defense and the Ministry of Science and Information and

Communications Technology to seek advanced digital technology and meet the nation's evolving defense needs through a joint R&D center (Kim, 2021). Furthermore, the government has introduced Defense Reform 2.0 strategy, which pushes for defense industry investment and innovation (Yeo, 2020). Also, to support the industry post-COVID recovery, the ministry drafted plans to adjust spending on indigenous products and move delivery timelines to reflect the reality of schedule delays while also waiving penalties for late-payments and have pledged to support research institutes and collaboration in defense-related development by increasing funding (Yeo, 2020).

Since its independence, it has centered its efforts on seeking self-sufficiency and economic/military independence (KAIST, 2022). South Korea explicitly expressed its plans to increase its arms exports and become the "Arms export market," thus boosting the economy's growth (KAIST, 2022). As such, KAIST made it part of its mission to assist in transforming the ROK into a global economic hub by intensifying and scaling its research initiatives (KAIST, 2022). Driven by that, the KAIST Institute (KI)[20] It was founded alongside centers, institutes, and labs (KAIST, 2022). Besides this, KAIST has formulated partnerships with global industry players and has constructed the Technology Commercialization Center to support startups with commercialization and find the right business partners alongside advisors and experts in distinct fields (KAIST, 2022).

4.2.5.Summary of South Korea Case

South Korea had a rough path to independence. It was invaded by the Japanese, Chinese, Mongols, and the Soviets at least. The last war recorded was the "Korean War", a proxy war between North Korea led by the Soviets Union and South Korea led by the UN. All in efforts to "contain the spread of communism". In 1953, the Korean Armistice agreement was signed between the two conflicted parties agreeing on ceasing fire and setting a demilitarized zone, causing the creation of the Democratic People's Republic of Korea (DPRK) in the north and the Republic of Korea (ROK) in the south, a dictatorship, and a democracy accordingly. The divide left ROK with few natural resources, an underdeveloped economy, poor infrastructure, and poverty. Poverty was caused due to refuge

20 is the hub of open innovation and inter-and multidisciplinary research. KI comprises six research institutes that perform trends analysis and predictions about significant policies, governance, and technology in the era of the Fourth Industrial Revolution.

influx from the DPRK, the loss of the leading agriculture importer (Japan), and the repatriation of Japanese skilled labor after the war. Therefore, %80 of ROK revenue came from US aid, sufficient to feed the population and assist military operations. Nonetheless, a great deal of aid was misused and targeted for private use and users due to corruption and favoritism in conducting businesses.

For this reason, a new wealth class called "Chaebols" was formed alongside the protectionism economic policy and import substitution policy. Theoretically, these policies were supposed to push for economic reform and growth instead, and due to favoritism, it crippled the economy and hindered its growth. Post-1961, education and land reforms were prioritized. Regarding education, the government with private groups partnered-up to provide literacy programs aiming to rapidly expand education which resulted in ROK having the best-educated workforce in the region. Another priority was land reform, and the government set new policies to eliminate tenancy and provide social stability leading to more money being spent on education, industry, and commerce. This has further pushed ROK to set its sight on "Abolishing poverty and eliminating foreign dependence" by exploiting nationalist agendas to push for economic reform. The first order was to detain and fine all corrupt leaders and then use their know-how, education, and experience in the field to build and develop the economy. They were hired and appointed to the Promotional Committee for Economic Reconstruction, which oversees the Economic Planning Board (EPB) and drafts the five-year development plan. The initial plan included nationalizing all banks, redirecting the import substitution policy, and offering low-interest loans for startups and business owners. This led to %8.9 economic growth and a %29 increase in the country's exports.

The success of the initial plan incentivized the EPB to draft another one focusing this time on enhancing the infrastructure and increasing FDI. During the same time, ROK noticed the flattering US commitments to its regional allies, the raising of China, and the increasing aggression in regional security infrastructure. This realization heightened the importance of self-reliance and shifted ROK's economic strategy to heavy industries and the upselling of technological capabilities and contracts.

Regarding our initial topic of interest, we looked at the character of South Korea's defense ecosystem and the State–Defense–University level of association and influence. Starting with

understanding South Korea's defense ecosystem by considering its maturity, scope, and structure and we concluded the following points accordingly:

- **Maturity:** Korea's ambitions of having a solid defense sector are traced back to 1953. During that time, Korea signed a mutual defense treaty w/US to import armory. Korea's military needs were fulfilled, yet it crippled ROK from developing its systems. The withdrawal of US troops from South Korea as part of Nixon's doctrine (despite persistent DRPK threats) and Vietnam (during an ongoing war) pushed the ROK to seek its independence and become a self-sufficient nation. The journey of South Korea's independence took multiple stages, first by introducing the Military Imports Substitution (MIS), where high investments were utilized to build infrastructure, concentrating on reverse engineering to build ROK's production platform and meet its basic needs. Then, the production evolved to host advanced weaponry, pushing for export promotion and relying heavily on R&D centers. Later, the government introduced the "Defense Reform 2.0" strategy focusing on export and shifting the ROK to grow into an "Arms Export Market".
- **Structure:** The Korean government depends on the private sector (contractors, mid-sized sub-contractors, chaebols) for defense industrialization. The government granted contracts for the private sector in primary industries like shipbuilding, steel, and electronics. From the government's perspective, it is offsetting potential losses from military-industrial production, essentially reducing sunk costs. For businesses, it is an opportunity to guarantee procurements, gain a competitive advantage, and lock in significant advance payments while facilitating tech innovation through the synergy of civil-military technology (dual-use tech). It is worth mentioning that corporate/large enterprise accommodates more than half of corporate R&D investments. In 2020, ROK assigned %4.81 of its GDP to R&D investments, around USD 75.4 billion, and %57.8, which is about USD 43.61 billion stemmed from the private sector. All funding must go through the Korean Council of R&D Funding Agencies. The council consists of many government entities to manage national R&D projects, evaluate milestones, build cooperation between organizations, and facilitate the exchange of information.

When it comes to the defense sector, its structure consists of government entities like the Ministry of National Defense, Defense Acquisition Program Administration (DAPA), ROK Chiefs of Staff, and the Agency for Defense Development, as well as private enterprises, universities, and research institutes. All stakeholders are working towards specific branches (i.e., cyber, IA..). In 2020, the ROK set %2.5 of its GDP (± USD 45.7 billion) to the defense sector, with %6.32 (± USD 2.89 billion) allocated exclusively to defense R&D. Referring to our case study, KAIST, R&D centers sponsorship within is distributed by %23.9 to %76 between private and government sponsorship accordingly.

- **Scope:** As mentioned earlier in the maturity point, the country has implemented five strategies reflecting its ambition during that period, as such:

  Startegy 1. Military Import Substitution; to establish a fundamental weaponry base.

  Startegy 2. Production Shift to include advanced weaponry systems: The shift was smooth thanks to the USD 6 million load provided by the US Agency of International Development, alongside the human capital assistance from the US and KAIST to supervise the shift from light to heavy industries.

  Startegy 3. Defense Reform 2.0 focuses on export and shifting the ROK to grow into an "Arms Export Market".

  Startegy 4. New Defense Science and innovation technology Act by DAPA aims to increase government-private collaboration, foster innovation, create open space for defense R&D systems, prioritize the fourth industrial revolution (i.e., IA, robotics, IoT, genetic engineering), a set a new defense budget for 2021 – 2025 to increase civilian participation in defense R&D.

  Startegy 5. Global Space and Military Power, ROK aims to become a global space power with the help of the private sector. Right after that announcement, the Hanwha group signed an agreement with KAIST to develop multiple commercial projects & space technology research.

We then looked at the State – Defense – University level of association and influence by examining joint/funded research centers for defense innovation, feeder programs for graduates, and support for the defense innovation within the university charter. We have concluded the following points:

- **Joint/Funded Research Centers for Defense Innovation:** Government entities and chaebols offer to fund. Since its establishment, ROK has assigned primary industries to the private sector. Hence, all R&D centers in/working with the private sector are by default working on defense projects. The projects are categorized into three genres, as such:
    1. Type A: Projects for Individual Basic Research: Assigned to universities and research institutes to conduct primary research for essential items.
    2. Type B: Projects for Specialized Research Centers: Assigned to specialized R&D centers to carry out the essential items and university findings.
    3. Type C: Projects for Introducing New Technologies: work alongside international institutions through cooperation to introduce new technology that countries refuse to export to ROK.

Research projects are assigned and worked on alongside other parties depending on their type. There are roughly 200 R&D centers within KAIST. Some are set up exclusively by the university (i.e., KAIST Smart City Research Center), others with chaebols (i.e., LG Electronics - KAIST 6G Research Center), and a few with international conglomerates (i.e., Saudi Aramco-KAIST CO2 Management Center). Nine centers are under the Institute of Security Convergence, and they exclusively operate for the defense sector.

Historically, all research centers were government-led to strengthen the national defense capabilities. Nowadays, due to the development of smart IT technologies (i.e., drones, IoT...), its universities and private sector-led with collaborate with the government sector, as seen in the Hanwha – KAIST recent partnership agreement. So, following the ROK declaration to branch into global spare and military power with the help of the private sector, KAIST & Hanwha group formed a partnership agreement. The agreement enables both entities to develop several

commercial projects to research space technology. It is a joint venture with commercialization initiatives and USD 8.8 from the group. Some of the ventures' projects is developing a low-orbit inter-satellite link (ISL).

- **Feeder Programs for Graduates:** ROK offers multiple programs in different majors ranging from military education to HR development and unit training. Several scholarship programs are also awarded to Koreans, minority groups, residents, and to say the least. Military commissioned education scholarship exists, but it is only granted to pre-enrolled individuals in the military. In KIAST, however, the Institution of Security Convergence provides three types of scholarship programs as follows:
    1. Military – University Cooperative Program: Its cooperation was established in 2011 between KAIST and the Military to offer an opportunity to obtain a graduate degree to military officers.
    2. Security Convergence Program: Founded in 2020 and offered to interested parties. The program aims to foster creative convergence talents equipped with security and defense core technology competencies.
    3. Non-Degree Short-Term Education Program: The program, as suggested, gives short-term courses in core technologies (cyber security, space systems, defense technology, energy...) to military officers and officials.
- **Support For the Defense Innovation Within University Charter:** ROK's government played a significant part in pushing and supporting defense innovation. It enabled the role of the commercial sector and, as such, increased its dependence on their production. Furthermore, it promoted the "buy Korean" strategy and endorsed it as a government while ensuring fair competition. Likewise, the government thrived at linking spin-off and spin-on and streamlining R&D investments. In addition, it urged its counterpart to develop dual-use technology that can be commercialized and utilized for civil uses. At the same time, KAIST made it part of its mission to assist in transforming ROK into a global economic hub by intensifying and scaling its research initiatives. KAIST has founded the KAIST Institute and developed an alliance with global players,

together with constructing the Technology Commercialization Center to support startups. The center aims to guide startups to commercialization by building their business connections through networking sessions and events. Moreover, it provides startups and small businesses with advisors and field experts. To sum it up, KAIST is setting initiatives and tools to support the advancement and growth of the ROK economy.

Chapter 5. Discussion

The dynamic nature of politics and foreign affairs is unpredictable, today's friend is tomorrow's enemy, and the volatile relationship heightens security threats and creates a security vacuum once exploited. One of the risks attributed to the fluctuation of foreign relations is supply chain disruption; this is an alarming risk, specifically if the country relies on imports of essential commodities and security/defense goods, as seen in the shortage of defense and weaponry systems faced by the Ukrainians in the Russian – Ukrainian war. With many other risks, this risk has pushed governments to seek dependency and become self-reliant by strengthening their domestic economy and building a resilient defense system.

Nevertheless, the question remains about the ways countries can achieve their needs. Governments had an issue fostering a national technological ecosystem and developing it to produce essential technologies. Moreover, they lacked the knowledge and expertise to produce native weapons and other national security-related technologies such as communication, sensors, and surveillance.

From observing our two case studies, we concluded several solutions that shifted both countries tremendously. The immediate solution is the governmental support for the defense sector, which is portrayed in the overall country's strategy and plan alongside financial incentives and rewards and cascading over to national universities and R&D institutes. The second solution is comprehending that the development of the defense ecosystem is not and cannot be a one-man show which means that governments have the responsibility to encourage private sector participation and construct an appealing FDI environment. The third and final solution is investing in human capital and education. Talent is perceived as one of the main building blocks to establishing, sustaining, and growing the defense sector alongside the economy.

In this research paper, we have examined R&D models from Singapore and South Korea 1) To make a meaningful contribution to countries (including the UAE) efforts at maintaining modern and efficient defense sectors; 2) To look at the extent to which they participate in their respective nation's defense sector; 3) To look at how the aid attempts to producing critical national security technologies; 4) To look at the influence of the government and defense sector on R&D centers within

universities, and university – government-industry integration; 5) To understand the mechanism by which these universities can play a meaningful role in their countries defense – industrial enterprise.

This research paper can be used as a benchmark study for other governments and entities within the defense ecosystem looking to branch out and grow. It can also provide countries with new means to diversify their economies since Singapore and South Korea have little to no natural resources. Nevertheless, they both have a stable economy with a strong – profitable defense industry. The paper also illustrates the role of R&D centers in guiding and shaping the country's overall strategy and policies.

We looked at the character of both countries' defense sectors and studied them using three factors: maturity, structure, and scope.

We have found that both countries are historically similar. They both share security threats, have been colonized or non-existent, are open to post-conflict risks and have little to no natural resources, healthcare, or education. However, both countries were striving for dependency and self-reliance. Singapore and South Korea were equally dependent on imports of defense and weaponry commodities; consequently, the size of their defense system was incomparable to developed nations.

Therefore, they have both drafted a robust set of objectives and milestones to boost the sector and set the funding bodies and government agencies to support it. Initially, their plans aimed at developing basic weaponry systems for defensive purposes then shifted to specialization. South Korea specialized in heavy industries while Singapore focused on achieving battlefield superiority on precision strikes, advanced networks, and unmanned systems. However, both countries emphasized university-industry collaboration, dual-use technologies, and commercialization.

Though they both have developed a funding structure to systemize and organize all funds and rewards, Singapore's funding structure differs from South Korea's structure. In Singapore, all funding (government, private sector, and international players) is directed and managed by the NRF, RIEC, and RIE. While in South Korea, all governmental funds are directed and managed by CORFA, while private sectors and chaebols are free to monitor, fund, and conduct research as they see fit. Another critical differences in the country's defense structure are that in Singapore, FDI is encouraged with designated multiple market entry routes; on the other hand, South Korea essentially encourages home-

grown companies and chaebols by promoting and partaking in the "Buy Korean" philosophy. It is worth noting that both countries' significant funding is from the private sector.

Based on the literature review, the military–university union was enhanced during WWII to equip the military defense platform and win the war. This means that funds were intensely directed toward the university's R&D centers. Those funds played a significant role in developing the facilities, recruiting talents, and sustaining R&D operations and the university's stream of revenue. This positioned the defense sector and its entities as the primary stakeholder and pushed universities to prioritize defense-related projects due to the rewarding incentives. Thus, they have a primary role within the countries' defense innovation ecosystem. To maintain an-active involvement within the defense sector and secure talent, universities introduced interdisciplinary courses to support military-civilian operations and integrate dual-use technologies, hence, a return on the long-term and continuous investment from the sector.

The character of a country's defense industrial sector (its relative maturity, structure, and scope) profoundly shapes the role research-intensive universities play in a country's defense innovation ecosystem.

Agree.

From our findings, we have concluded that the character of a country's defense sector shapes the role research-intensive universities play in a country's defense innovation ecosystem. The results indicate that the country's history plays a significant role, providing the country with space for trial, error, and growth. Moreover, it helps shape the country's structure, policies, and vision. Taking South Korea as an example, the ROK governments are trying to obtain independency and be self-reliant in critical – defense sectors; therefore, it has set its scope to achieve that through multiple milestones starting from securing primary weapons, production change, defense reform highlighting arms export, prioritizing fourth industrial revolution, to concurring global space and military power. The structure in place has then uncovered those milestones. The structure comprises the government budget, funding agencies, market players (universities, research institutes, private sector), administrative and management councils, and entities. Once the route is identified, the funds cascade to R&D centers to kickstart the

project. As per the literature review, the main reason KAIST was found is to facilitate sharing of technology, scientific innovation, and research with other governments. As per our findings, %76 of KAIST research is sponsored by the government, while %23.9 is by the private sector. Since the private sector works in hand with the government on governmental projects mainly due to the reasons discussed in the research, we can then suggest that there is a possibility that research conducted by the private sector within KAIST is for government-related projects. Accordingly, we can conclude and agree with our hypothesis.

We have also looked at the level of state control, funding, and intervention in the higher education and defense sectors by looking at joint/funded research centers within national universities, feeders' programs, and the support for defense innovation in the university charter in both countries.

We concluded that both countries' R&D centers and established by the governments and their counterparts. The main difference is that South Korea has made chaebols an essential part of the system. It was not a choice at the beginning. Despite that, the partnership was deemed fruitful for both players. Originally, R&D centers and programs were governmental-led – in both countries. However, nowadays, the private sector, alongside universities, are the main actors in leading the change with the government – collaboration in South Korea. Singapore and South Korea have equally established defense representatives, the ORTDS at NTU in Singapore and the ISC at KAIST in South Korea. The centers were established to facilitate industry-university cooperation, bridge the communication gap between the defense–education sector and lobbying for funds, and oversee all defense-related centers and projects. The key differences between the Korean and Singaporean centers are the type of research conducted. Singapore focuses more on data, electronics, and networks. In contrast, South Korea focuses more on heavy industries like Space systems & Technology, Defense Technology, Energy Systems, and so on, with defense technology being the highest research area of KAIST.

Besides, both centers are equally active in hiring new talent and diversifying their scholarship programs according to the country's needs with attractive incentives, post-graduate rewards, and guarantees'. The main dissimilarity between the programs is that in South Korea, it was limited to military officers, whereas Singapore had that option open since its creation.

Moving on to our last feature, we have noticed that there is support for defense innovation within university charters. Both universities' strategy reflects their government's vision. They both are pushing to work and collaborate with the private sector, universities, institutes, and global influencers. In addition, both universities seek to enrich their nations by utilizing their R&D findings. For example, South Korea has announced its new ambitions to grow its space defense. Following that, a new partnership was formed between KAIST institute and Hanwha Group, supporting that strategy.

Hypothesis 2: The level of state control, funding, and intervention in the higher education sector and the defense sector is a crucial variable. The higher state intervention, the more likely there is a symbiotic relationship between research-intensive national universities and the defense industrial ecosystem.

Agree.

Based on our literature review, universities are expected to partner with other education organizations and governments as it results in economic growth and partake in the modernization of the defense sector globally due to scientific and technological breakthroughs seen from R&D centers. Research projects were confined to defense-related topics and subjects as the defense community was the main sponsor. Moreover, the literature suggests that there are two types of universities, purely military academies that were established for the sole purpose of carrying out military research for war and wartime tech and innovation. Such universities are fully sponsored by the government. The literature also implies that South Korea's success is contributed to the collaboration between governments and universities, which in return pushed for the R&D center's growth and facilitated innovation and partnerships. Besides that, it insinuates that governments still depend on funding and public policy to influence, encourage and entice universities to conduct R&D projects for the defense sector. Despite the freedom offered to R&D centers and institutes to conduct their own research, funded projects are still being prioritized.

We have noticed a strong correlation between the government vision, the country's defense strategy, and the university's strategy. For instance, in Singapore, the government added digital defense as part of its comprehensive defense strategy in 2020 after a horrendous cyber-attack it endured in 2018. The introduction of the strategy was reflected in the SAF2040 vision. It commenced establishing the Digital Security & Intelligence unit while increasing its budget by %6.5 to reflect the necessary changes required. Since the defense industry occupies two chairs from the REIC, NTU's strategy stresses supporting government R&D's priorities set by REIC and RIE plan and pushing for industry-university collaboration, digital security projects proposed by SAF and pushed through RIEC will be worked on by NTU's R&D centers.

Consequently, universities in both countries offer scholarship programs that help maintain, market, and prolong this defense union. Most R&D centers within these universities are government-led and funded, and programs offered within the universities are created to support and enrich those centers. The existence of defense representatives on each campus presents the importance of defense sector innovation to these universities and provides a glimpse of the size of each university's program.

Chapter 6. Conclusion

The country's strategy drives a strong university–defense ecosystem connection. It can be classified as a top-down approach. However, from our findings, we could see some promises or initiatives to push for a two-way practical communication approach. This can be perceived distinctly in South Korea as the private sector is given more space to innovate and has been part of the country's constitution. The defense sector is a vital player in university's R&D centers, and the same can be said for the role played by these centers in the defense ecosystem. We can claim that the university–defense ecosystem line is blurred at this point as they are all part of one community feeding into one common objective.

Looking at an example from the UAE…

Khalifa University is the leading research university in the UAE, with several research centers working jointly with government entities. Research centers with Khalifa University focus on multidisciplinary sectors aligned with UAE and Abu Dhabi priorities. The defense sector can use findings from these centers, yet there is no clear announcement of collaboration between the defense sector and Khalifa University. This may be due to the sensitivity of the projects, data classification, and the ratio between national vs. international faculty (i.e., more nationals possibly result in more trust).

6.1. Limitations and Recommendations

The generalizability of the results is limited by the shortage of research and development facilities in the Arab Region, the UAE, and other Gulf Countries. Data within the MENA region is insufficient, which makes the process of reflecting the findings difficult. The methodological choices were constrained by time. Due to that, interviews were not considered to collect primary data, which hindered our understanding of universities' operational structure, and fully understanding if research is government-led– or university-led. This opens the space for further research on the economic wealth generated by R&D

centers and how R&D centers can be set as a robust tool for economic diversification and a country's specialization, particularly for oil-dependent countries like the UAE. South Korea and Singapore set a prime example of nations born from nothing and becoming everything.

References

References

AI-Youbi, A., Zahed, A. H., & Tierney, W. G. (2020). International Collaboration as a Catalyst for Change: The Case of Nanyang Technological University,. In *Successful Global Collaborations in Higher Education Institutions* (pp. 43-50). Springer, Cham.

Andersson, B. (2017, December 15). The story of how Singapore became a research nation. (Y. Sharma, Interviewer)

Andrew , T. T. (2013). Singapore's Defence Industry: Its Development and Prospects. *Security Challenges*, *9*(1), 63–86.

ASEAN Member States. (n.d.). *Singapore*. Retrieved from Centre for Social Innovation: https://sea-eu.archiv.zsi.at/facts/sea/singapore.html

CISA. (n.d.). *Defense Industrial Base Sector* . Retrieved from Cybersecurity & Infrastructure Security Agency : https://www.cisa.gov/defense-industrial-base-sector

Clippinger, E. M. (1964). Korea. *The Journal of Asian Studies*, *23*(5), 89-97.

CORFA. (2021). *Purpose of Establishment* . Retrieved from Korea Council of R&D Funding Agencies: http://corfa.or.kr/eng/main/?skin=intro_summary10.htm

Cornell University, INSEAD, World Intellectual Property Organization (CIWIPO). (2016). From Research to Innovation to Enterprise: The Case of Singapore. In *Global Innovation Index 2016: Winning the Global Innovation* (pp. 133 - 139). Ithaca, Fontainebleau, and Geneva: World Intellectual Property Organization.

DSG. (2020, Jan 17). *A design innovation culture to elevate Singapore's defence science game*. Retrieved from Design Singapore Council : https://www.designsingapore.org/stories/a-design-innovation-culture-to-elevate-singapores-defence-science-game.html

Government of Singapore. (n.d.). *Nanyang University*. Retrieved from Singapore Infopedia: https://eresources.nlb.gov.sg/infopedia/articles/SIP_91_2005-02-02.html

Graham, E. M. (2003). The Miracle with a Dark Side : Korean Economic Development under Park Chung-Hee. *Reforming Korea's Industrial Conglomerates*, 11-50.

Grevatt , J. (2021, April 01). *South Korea enacts law to transform defence R&D culture*. Retrieved from Janes.com: https://www.janes.com/defence-news/news-detail/south-korea-enacts-law-to-transform-defence-rd-culture_16639

Grevatt , J. (2022, February 21). Retrieved from https://www.janes.com/defence-news/news-detail/singapore-announces-65-increase-in-2022-defence-budget

Halperin , S., & Heath, O. (2017). *Political Research: Methods and Practical Skills.* New York: Oxford University Press.

Hantrais, L. (1995). *Social Research Update: Comparative Research Methods* . United Kingdom: Department of Sociology University of Surrey.

ICD Research. (2021). *Singapore Defense Market - Attractiveness, Competitive Landscape and Forecasts to 2026.* Singapore: ICD Research.

ISCR. (2021). *Background and Vision*. Retrieved from Institute for Security Convergence: http://iscr.kaist.ac.kr/english

ISCR. (2021). *EDUCATION*. Retrieved from Institute for Security Convergence: http://iscr.kaist.ac.kr/english/sub0302

ISCR. (2021). *Organization Chart*. Retrieved from Institute for Security Convergence : http://iscr.kaist.ac.kr/english/sub0201

ISCU. (2022). *Scholarship*. Retrieved from Republic of Korea Seoul Cyber University: https://www.iscu.ac.kr/global/eng/cont/admis_05.asp

Jae-Ok, P., & Moon, C.-i. (2010). Defense Innovation and Industrialization in South Korea. *SITC Policy Briefs*.

K12 Academics. (n.d.). *History of Education in Singapore*. Retrieved from K12 Academics: https://www.k12academics.com/Education%20Worldwide/Education%20in%20Singapore/history-education-singapore

KAIST. (2021). *Annual R&D Report.* Retrieved from Korea Advanced Institute of Science and Technology: https://www.kaist.ac.kr/en/html/kaist/012103.html

KAIST. (2022). *Research* . Retrieved from Korea Advanced Institute of Science and Technology: https://www.kaist.ac.kr/en/html/research/04.html

KAIST. (2022). *Research Center of KAIST*. Retrieved from Korea Advanced Institute of Science and Technology: https://www.kaist.ac.kr/en/html/research/040301.html

KAIST. (n.d.). *KAIST History*. Retrieved from Korea Advanced Institute of Science And Technology Archives: https://archives.kaist.ac.kr/eng/history.do#

Kim, F. (2021, October 05). *South Korea seeks to accelerate 'smart defense innovation'*. Retrieved from Indo-Pacific Defense Forum: https://ipdefenseforum.com/2021/10/south-korea-seeks-to-accelerate-smart-defense-innovation/

KoreaTechToday. (2021). *Hanwha, KAIST, Tech Industry*. Retrieved from KoreaTechToday: https://www.koreatechtoday.com/hanwha-partners-with-kaist-to-co-develop-space-technology-research/

KRIT. (2022). *Defense Technology Planning*. Retrieved from Korea Research Institute for defense Technology planning and advancement: https://www.krit.re.kr/eng/contents.do?gotoMenuNo=02010000#none

KRIT. (2022). *Defense, Science, and Technology Level Assessment* . South Korea: Lim Young-il.

Larson, D. W. (1989). *Origins of Containment: A Psychological Explanation.* Princeton University Press.

Mackenzie, J. R. (2019, March 25). *Repeatability vs. Reproducibility* . Retrieved from Technology Networks : https://www.technologynetworks.com/informatics/articles/repeatability-vs-reproducibility-317157

MINDEF. (2022). *Defence Science & Technology* . Retrieved from MINDEF Singapore: https://www.mindef.gov.sg/web/portal/mindef/defence-matters/defence-topic/defence-topic-detail/defence-science-and-technology

MINDEF. (2022). *MINDEF*. Retrieved from Government of Singapore: https://www.mindef.gov.sg/oms/imindef/mindef_websites/topics/totaldefence/about.html

Ministry of Trade and Industry. (2019). RETURNS TO RESEARCH AND DEVELOPMENT (R&D) AMONG FIRMS IN SINGAPORE. *ECONOMIC SURVEY OF SINGAPORE THIRD QUARTER 2019*, p. 9.

MND. (2022). *Defense Policy*. Retrieved from Ministry of National Defense: https://www.mnd.go.kr/mbshome/mbs/mndEN/subview.jsp?id=mndEN_030900000000

Mondeja, M. (2017). Notes on Singapore's Development Strategy. *International Immersion Program Papers*. Chicago, Illinois, United States: University of Chicago Law School .

Moon, C.-I. (1991). The Journal of East Asian Affairs. *THE POLITICAL ECONOMY OF DEFENSE INDUSTRIALIZATION IN SOUTH KOREA: CONSTRAINTS, OPPORTUNITIES, AND PROSPECTS*, *5*(2), 438-465.

Morgan, J. (2018, March 24). *How Beijing weaponizes 'comfort women' as propaganda tool*. Retrieved from Asia Times: https://asiatimes.com/2018/03/beijing-weaponizes-comfort-women-propaganda-tool/

MSC. (2021). *Scholarship*. Retrieved from MINDEF Scholarship Centre: https://www.mindef.gov.sg/oms/scholarship/scholarships-dms.html

Myers, M. (2000). Qualitative Research and the Generalizability Question: Standing Firm with Proteus. *The Qualitative Report, Volume 4, Numbers 3/4, March, 2000*, *4*(3).

Nanyang Technological University. (2018). *Nanyang Technological University.* Retrieved from Nanyang Technological University: www.ntu.edu.sg

Nanyang Technological University. (2020). *Facts & Figures.* Retrieved from Nanyang Technological University: https://www.ntu.edu.sg/about-us/facts-figures

Nanyang Technological University. (2021). *ORTDS*. Retrieved from Nanyang Technological University: https://www.ntu.edu.sg/ortds/about-us/our-journey

National Research Council. (2009). *21st Century Innovation Systems for Japan and the United States: Lessons from a Decade of Change: Report of a Symposium.* Washington, D.C. : DC: The National Academies Press.

National Research Foundation (NRF). (2021). *Research, Innovation and Enterprise 2025 Plan.* Singapore: Government of Singapore.

Nolan, S. (2022, Jan 25). *Inside Singapore's vision for its defence tech future*. Retrieved from govinsider.asia: https://govinsider.asia/innovation/singapores-vision-for-its-defence-tech-future-loke-mun-kwong/

NTU. (2022). *Scholarships* . Retrieved from Nanyang Technological University: https://www.ntu.edu.sg/temasek-labs/work-with-us/scholarships

NTU. (2022). *NTU 2025.* Retrieved from Nanyang Technological University: https://www.ntu.edu.sg/about-us/ntu-2025/introduction-to-ntu-2025

NTU. (2022). *Temasek Laboratories@NTU (TL@NTU)* . Retrieved from Nanyang Technological University: https://www.ntu.edu.sg/temasek-labs/about-us

Onchi, Y. (2021, November). *Aerospace & Defense*. Retrieved from Nikkei Asia: https://asia.nikkei.com/Business/Aerospace-Defense/South-Korea-chases-global-ambitions-in-space-and-defense

Parameswaran, P. (2020, February 24). *ASEAN Beat*. Retrieved from Diplomat Media Inc: https://thediplomat.com/2020/02/what-does-singapores-new-defense-budget-say-about-the-countrys-security-thinking/

Park , G. (2011, April 21). *The Advance of a Korean Institute: A Brief History of KAIST*. Retrieved from The KAIST Herald: https://herald.kaist.ac.kr/news/articleView.html?idxno=158

pieter, w. d., alexandra, k., & siemon, t. (2021, March). *SIPRI Arms Industry Database* . Retrieved from Stockholm International Peace Research Institute : https://www.sipri.org/databases/armsindustry

Robinson, M. E. (2007). *Korea's twentieth-century odyssey.* Honolulu: University of Hawaii Press.

Seth, M. J. (2017). South Korea’s Economic Development, 1948–1996. *Oxford Research Encyclopedia of Asian History*.

Smart, B. (2016). Military-industrial complexities, university research and neoliberal economy. *Journal of Sociology, 52*(3), 455–481.

Soares, S., Sousa, J., Pais, A., & Vitorino, C. (2018). Nanomedicine: Principles, Properties, and Regulatory Issues. *Frontiers in Chemistry, 6*, 360. Retrieved from https://www.frontiersin.org/articles/10.3389/fchem.2018.00360/full

Sohn, J.-y. (2018, March 13). *KAIST seeks expanded state funding for science, tech leadership vision*. Retrieved from The Korea Herald: http://www.koreaherald.com/view.php?ud=20180313000620

South Korean Government. (n.d.). *Independence Movement*. Retrieved from Korea.net: https://www.korea.net/AboutKorea/History/Independence-Movement

Tan , C., & Pak , T. (2011). Functional differentiation: A critique of the bilingual policy in Singapore. *Journal of Asian Public Policy*, 331-341.

Toh, M. (2008, November 04). *NUS versus NTU: Looking beyond the rankings* . Retrieved from The Straits Times: https://www.asiaone.com/News/Education/Story/A1Story20081103-97950.html

UNESCO. (2020). *research and development spending*. Retrieved from UNESCO Institure for Statistics: http://uis.unesco.org/apps/visualisations/research-and-development-spending/

United Nations. (1953). *THE KOREAN WAR ARMISTICE AGREEMENT*.

Wisdom, J., & Creswell, J. W. (2013). *Mixed Methods: Integrating Quantitative and Qualitative Data Collection and Analysis While Studying Patient-Centered Medical Home Models.* Rockville, Maryland: Rockville, MD: Agency for Healthcare Research and Quality.

Wong, T. Y., & Kannan, S. (n.d.). *Singapore: International Advocacy Toolkit* . Retrieved from The Association for Research in Vision and Ophthalmology: https://www.arvo.org/advocacy/resources/international-advocacy-toolkits/singapore/

World Bank. (2019, April 09). *The World Bank In Singapore* . Retrieved from The World Bank: https://www.worldbank.org/en/country/singapore/overview#1

Yeo, M. (2020). *Reform efforts in South Korea create ecosystem for defense industry growth*. Retrieved from Defense News: https://www.defensenews.com/top-100/2020/08/17/reform-efforts-in-south-korea-create-ecosystem-for-defense-industry-growth/

Yoon, L. (2022). *Politics & Government*. Retrieved from Statista: https://www.statista.com/statistics/745747/south-korea-national-defense-expenditure/

Zarroli, J. (2015, March 29). *How Singapore Became One Of The Richest Places On Earth*. Retrieved from NPR: https://www.npr.org/2015/03/29/395811510/how-singapore-became-one-of-the-richest-places-on-earth

Association of American Universities. (2013). Federal funding for social and behavioral sciences: Improving health, bolstering security, growing the economy, fostering innovation, improving our lives. Association of American Universities.

Boardman, P. C. (2009). Government centrality to university–industry interactions: University research centers and the industry involvement of academic researchers. Research Policy, 38(10), 1505–1516. https://doi.org/10.1016/j.respol.2009.09.008

Dong-Won, K., & Leslie, S. W. (1998). Winning markets or winning nobel prizes? KAIST and the challenges of late industrialization. Osiris, 13, 154–185.

Hantrais, L. (1995). *Social Research Update: Comparative Research Methods* . United Kingdom: Department of Sociology University of Surrey.

Geiger, R. L. (1992). Science, Universities, and National Defense, 1945-1970. Osiris, 7, 26–48. https://www.jstor.org/stable/301766

Mackenzie, J. R. (2019, March 25). *Repeatability vs. Reproducibility* . Retrieved from Technology Networks : https://www.technologynetworks.com/informatics/articles/repeatability-vs-reproducibility-317157

Myers, M. (2000). Qualitative Research and the Generalizability Question: Standing Firm with Proteus. *The Qualitative Report, Volume 4, Numbers 3/4, March, 2000, 4*(3).

National Research Council. (2009). *21st Century Innovation Systems for Japan and the United States: Lessons from a Decade of Change: Report of a Symposium.* Washington, D.C. : DC: The National Academies Press.

Smart, B. (2016). Military-industrial complexities, university research and neoliberal economy. Journal of Sociology, 52(3), 455–481. https://doi.org/10.1177/1440783316654258

Soares, S., Sousa, J., Pais, A., & Vitorino, C. (2018). Nanomedicine: Principles, Properties, and Regulatory Issues. *Frontiers in Chemistry*, *6*, 360. Retrieved from https://www.frontiersin.org/articles/10.3389/fchem.2018.00360/full

Turse, N. (2004, April 27). The Military-Academic Complex: Who's the Real National Champion? TomDispatch.Com. https://tomdispatch.com/nick-turse-arm-wrestles-the-military-academic-complex/

Wisdom, J., & Creswell, J. W. (2013). *Mixed Methods: Integrating Quantitative and Qualitative Data Collection and Analysis While Studying Patient-Centered Medical Home Models.* Rockville, Maryland: Rockville, MD: Agency for Healthcare Research and Quality.

Appendices

Appendix A: Interview notes

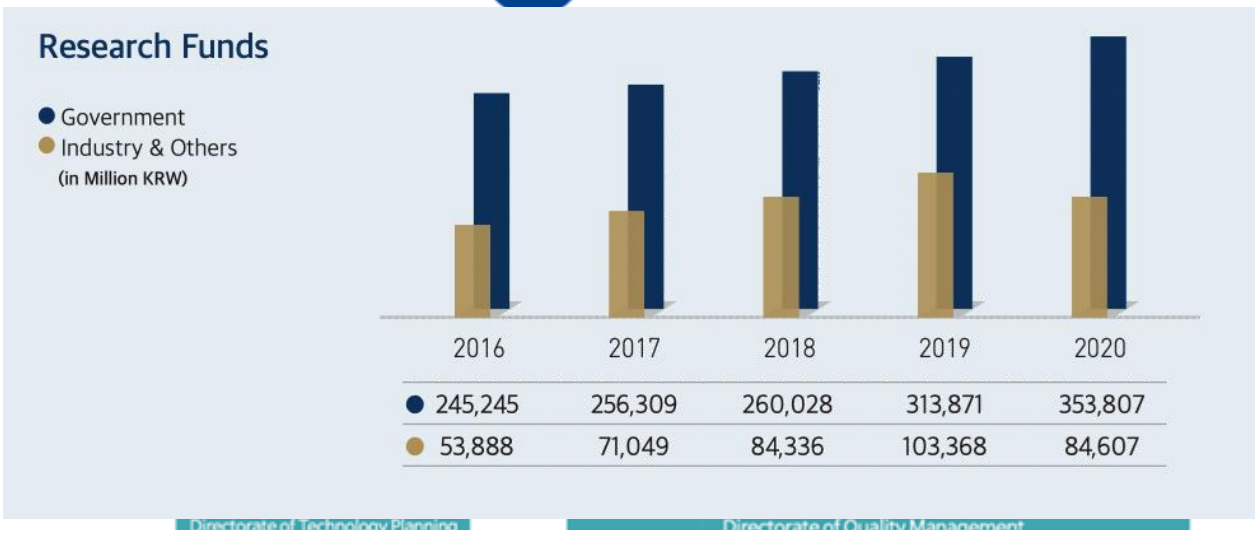
Notes from online interview between Maitha Aldhaheri and defense industry academic Richard Bitzinger, 27 Sept 2021

In a wide-ranging discussion on the Singaporean defense technology ecosystem and the role of NTU, Richard Bitzinger made the following points:

- The defense technology ecosystem is encircled by the government. This means that there is very little external commercial involvement in the defense scene.
- The key actors in the defense technology ecosystem are MINDEF (Ministry of Defense) and the Defense Science and Technology Agency (DSTA).
- The Singaporean defense industrial base is very niche. It mostly provides equipment for Singaporean land forces. Aircraft and naval vessels are largely imported.
- Bitzinger was unsure about NTU's role as to research and development of defense technologies. In his mind, NTU's main contribution was in providing the talent (engineers and scientists). He suggested that Bernard Loo of NTU should be contacted to talk about this further. [Ash to make initial contact].
- Bitzinger made a more general point about Singapore's national system of innovation which has relevance to the defense technology ecosystem and especially when we consider dual-use technologies, that is, emerging technologies that have both civilian/commercial applications and can be employed for national security purposes [quantum computing, AI, etc.]. He notes that whilst Singapore is a highly industrious city-state it has struggled to create up an innovative society. For more on this, see his recent article in Journal of Strategic Studies.[21]

[21] https://www.tandfonline.com/doi/abs/10.1080/01402390.2021.1947252?journalCode=fjss20

President



Research Funds 2016 - 2020 (source: KAIST)

Directorate of Technology Planning

Defense Venture Team

C4ISR Systems Division
- C4ISR Systems Research Team 1
- C4ISR Systems Research Team 2
- C4ISR Systems Research Team 3

Land Systems Division
- Land Systems Research Team 1
- Land Systems Research Team 2
- Land Systems Research Team 3

Naval Systems Division
- Naval Systems Research Team 1
- Naval Systems Research Team 2
- Naval Systems Research Team 3

Aviation & Guided Weapons Division
- Aviation & Guided Weapons Research Team 1

Directorate of Quality Management

- Quality Planning Team
- Quality Management Team
- Field Technical Support Team
- Parts Development Research Team
- Standardization Research Team
- Defense Quality System Certification Team

C4ISR Systems Center
- C4ISR Systems Engineering Team
- C4ISR Systems Team 1
- C4ISR Systems Team 2
- C4ISR Systems Team 3
- C4ISR Systems Team 4

Land Systems Center
- Land Systems Engineering Team
- Land Systems Team 1
- Land Systems Team 2
- Land Systems Team 3
- Land Systems Team 4
- Land Systems Team 5
- Land Systems Team 6

- PGM & Ammunition Engineering Team
- PGM & Ammunition Team 1
- PGM & Ammunition Team 2
- PGM & Ammunition Team 3
- PGM & Ammunition Team 4

Combat Materiel Center
- Combat Materiel Engineering Team
- Combat Materiel Team 1
- Combat Materiel Team 2
- Combat Materiel Team 3

Defense Reliability Center
- Firing Safety and Engineering Team
- Test Analysis Team
- Firing Test Team 1
- Firing Test Team 2
- RAM Analysis Team

Appendix B: Key research centers and institutes

Figure 7: Key research centers and institutes

Appendix C: NTU

Some of NTU's international academic partners

Europe

- CEA: French Alternative Energies and Atomic Energy Commission
- CNRS - Centre National de la Recherche Scientifique
- Copenhagen Business School
- ETH - Eidgenössische Technische Hochschule Zürich
- Fraunhofer-Gesellschaft
- Graz University of Technology
- Imperial College London
- Karolinska Institute
- King's College London
- KTH Royal Institute of Technology
- Medical University Vienna
- Norwegian University of Science and Technology
- Sorbonne University
- Technical University of Denmark
- Technische Universität München
- TNO (The Netherlands Organisation for applied scientific research)
- Universite Grenoble Alpes
- Universite Paris-Saclay
- University College London
- University of Bristol
- University of Cambridge
- University of Edinburgh
- University of Southampton
- Wageningen University

North America

- California Institute of Technology
- Carnegie Mellon University
- Cornell University
- Georgia Institute of Technology
- Massachusetts Institute of Technology
- Monterrey Institute of Technology and Higher Education
- Northwestern University
- University of British Columbia
- University of California, Berkeley
- University of California, Los Angeles
- University of Toronto

Asia and beyond

- Australian National University
- Chinese Academy of Sciences
- Chulalongkorn University
- Fudan University
- Gadjah Mada University
- Hebrew University of Jerusalem
- Hong Kong University of Science and Technology
- Indian Institute of Technology Bombay
- Indian Institute of Technology Madras
- Korea Advanced Institute of Science and Technology
- Kyoto University
- Mahidol University
- National Taiwan University
- Osaka University
- Peking University
- Seoul National University
- Shanghai Jiao Tong University
- Technion-Israel Institute of Technology
- The University of Hong Kong
- Tokyo Institute of Technology
- Tsinghua University
- University of Melbourne
- University of New South Wales
- University of Tokyo
- University of Malaya
- University of Indonesia
- Vietnam National University, Ho Chi Minh City
- Zhejiang University

Appendix

NTU achievements

Year	Achievement
1988	MOU signed between NTI & MINDEF to co-found a small scale research projects in Defense.
1993	MOU signed with MINDEF to expand collaborative scope and activities.
1998	Setup of Protective Technology Centre
2001	Setup Center for Research in Satellite Technologies
2003	Setup of Temasek Laboratories @NTU
2006	Setup of Electromagnetic Research Laboratory
2008	Setup of Energetics Research Lab
2010	MOU was signed between NTU and MHA on Building Security
2011	Joint Venture in ST Electronics (Satellite Systems)
2013	Second MOU with MHA to broaden topics of collaborations
2014	Co-set up of Centre for Optical Fiber Technology
2015	Setup of Office of Research and Technology in Defense & Security
2017	MOU signed with Cyber Security Agency of Singapore
2019	Signed MOA with CSA to setup National Integrated Center for Evaluation

NTU landscape