Technological Forecasting & Social Change 146 (2019) 1–11

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Rethinking the national defense R&D innovation system for latecomer: Defense R&D governance matrix

Jun Gon Lee, Min Jae Park*

Department of Business Administration, Seoul School of Integrated Sciences and Technologies (aSSIST), 46 Ewhayeodae 2-gil, Seodaemun-gu, Seoul, Republic of Korea

ARTICLE INFO

Keywords:
Defense R&D
R&D governance
Latecomer
National Innovation System
Decision-making process

ABSTRACT

The purpose of this study is to present defense R&D governance model for governance analysis and decision making in defense R&D programs. In particular, by utilizing the MIT Sloan IT governance matrix and through Delphi surveys of a group of defense R&D experts, an efficient governance model of national R&D and weapon systems acquisition area is deducted and at the same time policy implications and directions of defense R&D and weapon systems decision making processes for technology-pursuing countries are presented. This study contributes to the decision making of R&D and weapon systems acquisition programs that utilize defense R&D governance, by allowing many corporations trying to enter emerging economies to understand those countries' defense R&D governance models. This study emphasizes that the governance with the most optimal combination of the Decision types (R&D Principles, R&D Architecture, R&D Infrastructure, Business Application Needs, R&D Investment) and the Archetypes (National R&D Committee Monarchy, Defense Agency Monarchy, Federal, Defense Industries Monarchy) must be reflected on national defense R&D programs and weapons systems acquisition procedures, in accordance with the scale and budget of a given program. This can be applied through various means to benefit national defense R&D and weapons system-related projects in different countries.

1. Introduction

The defense industry, as an industry of regulations and procedures to execute R&D and weapon systems acquisition programs with planned defense budgets, has been continuously developing in detail according to each country's policies (Davies and Hobday, 2005). In particular, the defense industry is large and diverse in terms of the program scale and budget size, and all programs must be executed within regulations and procedures, from the long-term requirements phase to program execution procedures and decision-making processes per each phase. Occasionally, due to the nature of the defense industry, the structure and program execution decision making processes may not be flexible, and flexibility or innovation is seen only in a restricted form, meaning a lot of reviews and time spent on many unforeseen aspects when various changes occur (Malik, 2018). In order to overcome this problem, it is important to execute R&D programs by deducting the best possible acquisition methods through a process of mixed consultation and agreement that crosses boundaries between other related agencies in the field of science and technology, including related defense agencies, through defense R&D governance from the program's initial planning phase for related technology that is to be acquired (Cho et al., 2016; Henriksen and Ponte, 2018).

Eventually, this allows for effective execution and program management in all areas including budget, development period and level of technology acquired, by managing a program's foreseeable dangers from the initial phase. In this regard, the application of innovative defense R&D governance must be considered as a compulsory factor. Governance is concerned with developing and implementing appropriate structures and processes for directing and managing an organization so that stakeholders can be assured that the department is operating effectively and efficiently (Mowery, 2010). The definition of defense R&D governance is based on the assumption that defense-related parties are involved in mutual cooperation to resolve and manage issues related to research and development with related organizations in a series of processes ranging from initial research stage to practical use of defense science and technology method (Godoe, 2000; Hendrickson et al., 2018).

Defense acquisition systems are usually categorized into four broad concepts (Fox and Field, 1988). These include 3 categories in the R&D and acquisition area – what to acquire (R&D/weapon systems requirements), when to acquire (yearly planning and budgeting) and how to acquire (acquisition methods and program execution) – and plans for stable follow-up logistics support after completion of development and production & deployment. Since this entire acquisition process and

* Corresponding author.
E-mail address: mjpark2@assist.ac.kr (M.J. Park).

https://doi.org/10.1016/j.techfore.2019.05.012
Received 15 September 2018; Received in revised form 10 April 2019; Accepted 7 May 2019

program execution system is connected with a single link, decision making from the initial phase through defense R&D governance is of highest importance, and this is directly linked with the development and growth of each country's defense science and technology. Questions that may be deducted for this study are as follows:

1. Does government-wide governance between governmental organizations for decision making in defense R&D and weapon systems introduction programs exist?
2. Is there any way to conduct efficient review and discussions at the intergovernmental level on core technology and weapon systems to be acquired within regulations and procedures from the initial phase of program execution?
3. How should defense innovation systems be formed?

The ultimate goal of defense R&D governance is to develop the fastest and most effective method that allows the military branch requiring weapon systems to operate them. To do this, considering the characteristics of the defense industry, governance (including defense decision making processes) is being executed, led by defense related organizations. However, governance needs to be applied at the national level for the most effective decision making in situations where national R&D is being executed and developed at various branches in the government, and action needs to be made quickly against new changes in national defense, including technological innovation of science and technology performance and convergence at the national (as well as social and economic) level, by establishing an integrated national science and technology coordination scheme. In particular, Defense R&D is a risky undertaking as the outcome is uncertain; therefore, decision makers should incorporate flexibility into investment decisions (Mowery, 2010; Stowsky, 2004). From the past, there has been a historically and regionally close relationship between the defense industry and politics/diplomacy. Especially in defense, due to the nature of the industry, there have been continuous efforts to acquire capabilities for the development, improvement, production and operation of weapon systems through independent R&D by fully utilizing each country's own abilities instead of relying on foreign countries (Rotblat et al., 2016).

Ultimately, the defense industry is connected to direct national power and diplomatic power, symbolic of strong countries, and from this standpoint the recent process of negotiations for denuclearization on the Korean Peninsula through the US-North Korea summit meetings cannot be seen as entirely unrelated. Therefore, beyond just a means of defense for the comfort and survival of a country, the importance of the defense industry's growth engine, combined civil-military technology development and mutual application will gradually increase, and we can eventually say there has been a transition of strategy that goes beyond national security and the improvement of military combat capabilities to policies that simultaneously consider the national industry and economic growth (Kollias and Paleologou, 2017). Internally, considering the defense industry's unique nature, transition needs to be made to defense R&D's innovation system with a synergy effect through inter-industrial cooperation, and externally, we can expect the defense industry to play the role of an economic growth engine through policies to develop and grow in the export market with technology that has been accumulated and secured (Desli et al., 2017).

The purpose of this study is to present defense R&D governance model for governance analysis and decision making in defense R&D programs. In particular, by utilizing the MIT Sloan IT governance matrix and through Delphi surveys of a group of defense R&D experts, an efficient governance model of national R&D and weapon systems acquisition area is deducted and at the same time policy implications and directions of defense R&D and weapon systems decision making processes for technology-pursuing countries are presented. This study may contribute to the decision making of R&D and weapon systems acquisition programs that utilize defense R&D governance, by allowing many corporations trying to enter emerging economies to understand those countries' defense R&D governance models.

The sequence of study is as follow. In Section 2, the characteristics of and challenges to the defense R&D area are presented along with existing studies on governance and decision making. Next in Section 3, the R&D governance matrix is presented based on current literature, and the components thereof are explained. In Section 4, the presented framework is actually applied to the situation in the Republic of Korea, and appropriate governance types per decision making type are presented by utilizing the Delphi method. Based on the above results, Section 5 Discussion draws the implications of this study, and finally in Section 6 the limitations of the study and future research are presented.

2. Literature review

2.1. Latecomer's challenges in defense R&D

Compared to other industries, the defense industry designates programs that develop and produce all sorts of articles that are either directly or indirectly necessary militarily for national defense (Mowery, 2010). It takes the form of a major government-led industry that develops, produces and maintains weapons, among other articles required in the military, which are critical to enhancing defense capabilities. The latecomer advantage that arises from latecomers' pursuits in general is not applicable in this industry. The unique nature of the defense industry explains this in detail.

First, the defense industry is closely related to a country's political and military goals, and defense budget distribution and expenditure, necessary for securing the economic and technological foundations required for investment in the defense industry, are extremely flexible depending on tensions with neighboring countries (Karabag and Berggren, 2016; Mowery, 2010). Furthermore, measurement of the investment effect that is emphasized in other industries has a structural limitation in the defense industry since a reasonable amount of profit is guaranteed by the government. Especially in the case of latecomers in the defense industry, opportunity costs of political and social competition for the limitation and finitude of available resources and priorities in distributing resources, along with political and military motives, are triggered (Li, 2010). This has the side effect of reducing expenditure in other areas such as welfare, and at times the impact of surrounding politics and lowering of tension with neighboring countries lead to sudden changes in budget distribution and policies.

Second, unlike other civilian areas, the defense industry is by nature a strategic national security industry. Trebelicock (1969) and Christensen (1989) stated that the defense industry has the multiplicity of not only strengthening forces in the military and state of the art technology acquired through defense-related R&D having a spillover effect on civilian industries, but also contributing to the national economy through the export of defense articles (Moretti et al., 2014; Plummer and Gilbert, 2015). However, strategic articles related to the defense industry are categorized as a country's strategic assets and are subject to control by that country and the component's exporter. The Coordinating Committee for Multilateral Export Controls (CoCom) was established by Western bloc powers in the first five years after the end of World War II, during the Cold War, to put an arms embargo on countries. In the United States, CoCom compliance was implemented in the 1960s via the Arms Export Control Act (AECA) and the State Department's regulatory supervision on AECA via International Traffic in Arms Regulations (ITAR), which are still in effect. ITAR is a U.S. regulatory regime to restrict and control the export of defense and military related technologies to safeguard U.S. national security and further U.S. foreign policy objectives. Europe and countries that export weapons also apply strategic weapon export control laws by considering the situation of each country. They manage and control the export of technology-related intangible assets such as technology transfer, intellectual property rights etc. and tangible assets like defense articles (Bontis, 2001; Kaplan et al., 2004). The defense industry is a capital-intensive industry that involves immense capital investment and is also a technology intensive industry that requires highly complex technology and precision. Defense articles, due to the distinct characteristic of their use, are a supply market led by advanced countries and planned, developed and produced by state-of-the-art technology, and control on technology transfer of advanced weapon systems is continuously being reinforced (Kaplan et al., 2004). Such characteristics of defense industry are based on international political relations in each country. In other words, global dependency has a great impact on national Defense R&D strategy (Neuman, 2010).

Third, when looking at the global conditions and environment that the defense industry currently faces, we see that in the past war took the form of mass destruction and casualties at its center due to the development of advanced military science and technology, but since the latter half of the 20th century a new form of war has risen, one in which victors of war have minimal death and destruction. As a result, future warfare will be affected by the fourth industrial revolution and strategic concepts, operations and tactics of the future combat environment are expected to determine the outcome of war, having been expanded based on command and control, long-range precision strike, manned/unmanned cooperative systems, artificial intelligence etc. which have incorporated state of the art science and technology (Burmaoglu and Sarıtas, 2017; Coccia, 2018). Therefore, regarding defense R&D and weapon systems, the global trend for advanced countries and latecomers alike at the national level is focused on self-development of weapon systems, which are key forces in future warfare. However, advanced countries avoid the transfer and sale of military technology even to allies and continue to invest vigorously in defense R&D to secure original, core technology (Coccia, 2018). Such internal and external environments are factors that pose as challenges to the technological pursuits of latecomers and make it difficult to overcome the technological gap with advanced countries (Lee and Yoon, 2015). It is time for a new R&D strategy for latecomers to search for ways to secure core technology of which advanced countries are avoiding to transfer and sell.

Looking at the global defense industry's current status, among the 2016 SIPRI Top 100 arms-producing and military services companies in the world (excluding China), there are 44 US companies and 28 European companies, which adds up to a total of 72 companies in the US and Europe; by contrast, there are only 17 Asian companies (including Australia). This is closely related to the defense industry's generational history and global dependency. During the years surrounding the first World War, the US and European countries such as US, UK, France and Germany began to lead the defense industry and have done so until the present day, and latecomers including Korea who entered the industry after the second World War are continuously nurturing and growing the defense industry, and are included in the upper tier in terms of defense expenditure within the global defense market.

However, compared to other industries, there still remains a gap between advanced countries and latecomers in the area of core technology and weapon systems acquisition methods, something that is not expected to be easily overcome in the short run. This can be explained by the continuous increase in defense budgets and globalization of the defense industry. After the post-Cold War era in the latter half of the 20th century, the world met globalization of weapon development, production and marketing, and a movement away from weapon production by a single country to the form of a global market is gradually on the rise. Advanced defense industry countries, in order to occupy in advance and pioneer breakthroughs in the export market, are trying to establish a global sourcing network and regional posts. In order to disperse investment cost and risk and to strengthen the marketing capabilities of the defense industry, M&As of global defense industries, R&D in defense articles and international cooperation and strategic partnerships in certain defense areas are being executed. In particular, through a development method known as Risk Sharing Partnership (RSP), joint investment methods have been occasionally selected by sharing risks such as development and nurturing costs and by distributing future sales profits according to the investment ratios (Figueiredo et al., 2007).

Also, the example of the F-35 fighter aircraft development by inviting joint development investors' investments and the Republic of Korea Air Force's KF-X next generation fighter program are some good examples of joint development through the invitation of investors like the Indonesian government and system OEMs. Therefore, latecomers who are facing this global environment must search for ways to transition to globalization of the defense industry in order to increase the industry's efficiency, and there needs to be efficient decision making in industrial cooperation and defense R&D governance. This makes it possible to cover both security and national economic industry, by combining and commercializing advanced countries' state of the art technology to pave new roads and expand to the economic, industrial areas to go beyond the defense industry's current level of national security. Based on the global history and the international relations of the defense industry, not only endogenous factors have been affected but also exogenous factors such as international relations have been significant (Neuman, 2006).

2.2. Defense R&D innovation governance system

"Innovation is change that creates a new dimension of performance." (Drucker, 2014). Continuous innovation is recognized as a compulsory condition for future growth in the global economy. Especially, ever more emphasis is placed on the importance of innovation, which plays a key role alongside the creation of new technology that accompanies economic growth when aiming at the global market. As a result, questions regarding R&D and productization of new knowledge, research-oriented universities that pursue the combination of knowledge and commercialization, and how to establish industry-academic innovation clusters based on such universities have become key issues of government policy. The status and areas of innovation policies of major countries, including OECD countries, are also changing. Countries consider innovation policies as key policies for governance in all aspects, including the society and economy, and are emphasizing the status and role of innovation (Guo et al., 2018; Lee and Fong, 2018).

They are transitioning innovation policies to substructure type policies which form the foundation for policies in all areas, not just to the restraints of science and technology. Innovation policies, which were traditionally focused on development in science and technology and the nurturing of industry, have expanded to areas such as labor, finance, environment, regional development, health and medical treatment and etc. (Nill and Kemp, 2009). OECD and EU countries are responding to such changes by introducing new innovation policy perspectives and are emphasizing the importance of innovation governance as a key agenda. Innovation and technology development are the result of a complex set of relationships among actors in the system, which includes enterprises, universities and government research institutes (Johnson, 2008). For policy-makers, an understanding of the national innovation system can help identify leverage points for enhancing innovative performance and overall competitiveness. It can assist in pinpointing mismatches within the system, both among institutions and in relation to government policies, which can thwart technology development and innovation (Etzkowitz and Ranga, 2015; Mowery, 2010). Policies which seek to improve networking among the actors and institutions in the system and which aim at enhancing the innovative capacity of firms, particularly their ability to identify and absorb technologies, are most valuable in this context. The core of the innovation system theory is that technological change comes not only from a single company or research institute, but also with the interaction with the social structure of the enterprise or research institution. The importance of innovation governance is emphasized by promoting innovation policy, which was relatively less important than economic policy and industrial policy, as the core of state administration. The current edition of the Oslo Manual identifies four types of innovation (Bloch, 2007):

- **Product innovation**: the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.
- **Process innovation**: the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.
- **Marketing innovation**: the implementation of a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing.
- **Organizational innovation**: the implementation of a new organizational method in the firm's business practices, workplace organization or external relations.

Due to the nature of the defense industry, the strong will of the government is compulsory for innovation in technology and institutional improvement through defense R&D innovation governance. In general, the majority of latecomers to the defense industry face many limitations in reality in the execution of economic and industrial development policies and efficient export policies (Lee and Yoon, 2015), because of factors such as immense investment costs, high development risk and a restricted market etc. when expanding defense R&D. Within the worldwide phenomenon of defense industrialization, unlike the post-Cold War era in the past when investment in military expenses were solely focused on strengthening military power, continuous investment in the defense industry is possible only when new methods to contribute to civilian technology and economic development are searched for. Therefore, advanced countries have regarded the defense industry as a national strategy industry and have continuously pioneered new roads by combining and commercializing state of the art technology. However, latecomers have developed from “advanced countries-following” to “advanced countries-pursuing” type countries and are showing a trend of transitioning to a “defense market leading” paradigm that contributes to the national economy and gradually leads defense exports (Mowery, 2010). Therefore, there is a search for ways to increase R&D efficiency and improve the defense industry's external competitiveness through the defense industry's globalization, comprised of introduction and joint development of state of the art technology in cooperation with advanced countries.

In the US, the defense Innovation Board (DIB) is one of several independent federal advisory committees advising the Secretary of Defense on various issues. Focusing less on long studies and more on rapidly producing action plans and experiments, the DIB makes its proposals through the prism of three major challenges: people and culture; technology and capabilities; and practices and operations. The DIB is part of the larger, emerging innovation ecosystem at DoD and the mission is to provide the Secretary of Defense, Deputy Secretary of Defense, and other senior leaders across the Department with independent advice and recommendations on innovative means to address future challenges. One of the cases that is often mentioned as having innovative R&D is the Defense Advanced Research Projects Agency (DARPA) under the Department of Defense. DARPA has garnered much attention with a series of innovations such as internet, stealth aircraft, GPS and the da Vinci robot. One of the most important factors that define the DARPA creative culture and explain its long and continuing history of innovation are Trust and autonomy Risk-taking and tolerance of failure (DARPA, 2016). A culture of innovation that is rooted at the highest levels of DoD is required and each echelon of the Department must be structured to rapidly adapt and field capabilities that leverage the advances that are occurring at an ever increasing pace in the commercial and defense technology sectors. The US defense R&D system's key strategy lies in inducing active joint development and broad activation of related industries and securing and maintaining a technological advantage through the development of new state of the art technology, innovative research and organizational management.

Table 1
The main exporters and importers of major weapons.

	Exporter	Global share (%)
1	USA	33
2	Russia	23
3	China	6.2
4	France	6.0
5	Germany	5.6
6	UK	4.6
7	Spain	2.8
8	Italy	2.7
9	Ukraine	2.6
10	Israel	2.3

	Importer	Global share (%)
1	India	13
2	Saudi Arabia	8.2
3	UAE	4.6
4	China	4.5
5	Algeria	3.7
6	Turkey	3.3
7	Australia	3.3
8	Iraq	3.2
9	Pakistan	3.2
10	Viet Nam	3.0

Source: SIPRI Arms Industry Database (2017).

This situation and reality is also recognized in Europe and on November 2017 EU countries agreed on the big framework for strengthening military operational capabilities and jointly invested in new weapons and military equipment development through the Permanent Structured Cooperation on Security and Defense (PeSCo). The European Defense Agency (EDA) suggests to jointly develop weapons and equipment which can create a synergy effect and to systematically monitor the military budget and procurement plans of member countries to reduce duplicate investments. EDA's innovation strategy is one that promotes continuous innovation of the defense area, procedures for collaboration between EDA member countries and activation of technological innovation to make various research activities and participant by agents possible to develop and occupy future technology in advance. Defense R&D systems of the majority of latecomers to the defense industry have the pursuing structure of applying, developing and purchasing weapon systems from advanced countries. As shown in Table 1, among the rankings of main exporters and importers, the top 10 importers are comprised of countries other than the US and European countries; on the other hand, 6 countries, i.e. 60% of the top 10 exporters, are advanced countries including the US and European countries.

In the end, the direction of compulsory strategies to secure competitiveness for latecomers' defense R&D and weapon systems development is to consider important factors for the operation of defense R&D governance which sets defense R&D innovation policies and directions. This needs to be based on military strategy and operation concepts that take into consideration the defense budget and current level of technology (Christensen, 1989). From the perspective of not only the aspect of securing technology but also innovation, long term macroscopic policies that consider policy innovation governance, such as collaboration with advanced countries, needs to be established for weapon systems acquisition direction, economic efficiency, selection and concentration and global markets (Karabag and Berggren, 2016; Li, 2010). The innovation capabilities of open innovation, a globally new technological innovation trend, convergence between technologies and disruptive technology development and etc. need to be utilized in the

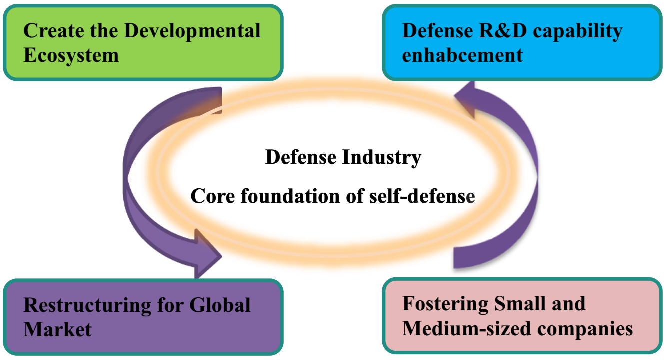

Fig. 1. 2018–2022 defense industry development mater plan.

civilian sector that has seen rapid growth and has been openly searched for. As the Fig. 1 shows, in Korea there is a transition from the current stable, pursuing type of R&D to a challenging, leading type R&D to strengthen defense R&D capabilities. It is improving R&D planning systems connected to the fourth industrial revolution so that future-oriented defense technology may be incorporated in other departments' R&D programs and is attempting to create a new future technology development system, as well as a new key technology development system that is not based on weapon systems requirements through related laws and regulations (Mowery, 2010).

Through system improvement and government level inducement to apply advanced civilian technology and policies which actively utilize national R&D capabilities, activation of practical civilian technology cooperation programs to utilize advanced civilian technology in the military, expansion of participation in defense programs and more flexibility of defense R&D systems for smooth execution is required. Moreover, consistent policies for effective and stable key technology R&D through continuous expansion of investment in defense R&D budget need to be executed (Henriksen and Ponte, 2018).

2.3. R&D governance and decision-making

Globally, a country's R&D innovation policies and innovation governance reflect a country's unique historical and institutional characteristics, and these go through a process of continuous change in response to changes in internal and external environmental factors that interact with innovation activities (Cho et al., 2016). Although these are collected as a certain form of governance, there is a difference to what is actually operated according to the contextual situation of a society and the unique institutional legacy of a country (Boekholt et al., 2002. Since the 2000s governments have recognized innovation governance design, as a result of raising the status and expanding the area of innovation policies, as a key priority task and have gone through various attempts. They present the realization of *"Integrated Innovation Policy"* and *"Broad-based Innovation Policy"* as main policy directions and emphasize the overall planning of innovation policies, strengthening the function of adjustment, increase of connection and integration between related departments, securing policy intelligence, and increasing the incorporation of social requirements (Burmaoglu and Sarıtas, 2017).

Furthermore, going beyond classic science and technology administrative systems, there is a search for how to establish the problem of connection and integration of innovation agents from the National Innovation System (NIS)'s perspective (Boekholt et al., 2002; Kuhlmann and Edler, 2003). Governance, as an institutional mechanism that affects individual and group behavior, includes cultural aspects such as members, relations between members, distribution of resources, the structural aspect of an organization, and rules and regulations (Davies and Hobday, 2005). Innovation governance is a subservient unit to governance of a country, and has the primary goal of economic development and the strengthening of national competitiveness based on technological innovation through R&D. If the overall concept of technology and institution that leads to technological innovation is phrased as NIS, innovation governance is a component of NIS.

As R&D policies are expanded from just one of many policy areas per department to innovation policies that are the foundation for all policies, the concept of innovation governance is also continuously expanding (Coccia, 2018). More emphasis is laid on the formation and execution process of policies rather than the contents of individual innovation governance policies, and focus is put on interaction among various actors to decide together the priorities, strategies, activities and results of innovation. It involves the complexity and management of decision making flows and tangible/intangible resources, and fundamentally adjusts mutual dependence, connection, network, partnership, co-revolution and mutual adaptation (Etzkowitz and Ranga, 2015). Governance brings a change to systems by newly presenting or realigning the priority of policy goals and means, and newly forming actors of policy network, functions and structural interconnection. From the fact that the concept of innovation governance emphasizes the process more than the contents and that it includes both structural and cultural aspects, innovation governance design may be understood as meaning the execution system and related rules design for the formation and execution of policy. According to Arnold (2004), adjustments related to innovation policies of a country are carried out at four levels.

First, level 1 policy adjustments are high level, government-wide policies, and are at the uppermost level. This is the phase where the general direction and priorities of the entire NIS are set, and governments either receive assistance from various experts or utilize means with binding power such as decision making through government committees. Level 2 policy adjustments are the phase where policies are adjusted between government departments. At this phase, adjustments are mostly based on government departments' missions. If adjustments are not made, there is a tendency for each department to pursue independent policies with responsibilities in each area. At this level, interdepartmental government groups occasionally function as adjustment mechanisms of level 1, in areas such as administrative aspects and/or policy issues. Level 3 has a more functional/executional characteristic and pursues the consistency of funding organization activities. Moreover, this may include not only administrative adjustments of funding activities but also more practical adjustments such as joint program planning. Finally, level 4 is the phase where we see actual research and innovation as well as adjustment between research/innovation agents. This level of adjustment tends to be executed through self-organization rather than utilizing official mechanisms.

The network of science, technology and policy has gone through a structural reform; now entities that do not belong to the scientific and technological fields, such as users, consumers, civil organizations and the general public, can participate in the policy-making process, whereas, in the past, only the R&D-related innovation entities, such as companies and R&D institutes, were allowed (Henriksen and Ponte, 2018). Now that an innovation policy has to be more than a supplier of technology and considering the socio-economic demands, its transparency and responsiveness have been more emphasized, and the big question is on how to link and integrate innovation facilitators within a complex system (Johnson, 2008). This is especially true in the R&D governance for national defense; an organic organizational system should be established for the sake of open R&D. In addition, there have been changes to the types of elements that countries pursue for national defense, in accordance with the changes to the patterns of war.

Therefore, it is imperative that the foundation for self-reliance in national defense be laid out by securing the capability to develop state-of-the-art weapons of new technology and new concept, all of which can be achieved through selecting certain pieces of cutting edge technology for future warfare and intensively developing them on a strategic level (Coccia, 2018). As for national defense-related R&D, which requires superior technological competitiveness, its planning must be expanded to include in projects various researchers with innovative ideas; an open format based on closer cooperation between the industry and the academia should be created. Furthermore, the assignment of roles among R&D entities must be accomplished so as to effectively bring in technological innovation in the area of national defense R&D.

Table 2
Description of archetypes in IT governance matrix.

Archetype	Description
Business monarchy	Individual or board of directors (excluding independent activities by IT officers)
IT monarchy	Individual or board of IT officers (group of IT experts)
Feudal	Leader of each business unit
Federal	Coalition of executives and business representatives
IT Duopoly	Leaders of IT office and business office
Anarchy	Individual or small decision-making group

3. Model development

This section presents the research model, by which one can analyze governance for national defense R&D. Weill & Ross' IT Governance Matrix (Weill and Ross, 2004) was modified and used in order to draw implications regarding the overarching decision-making entity of national defense R&D governance. This model is based on IT governance-related case-studies conducted on 256 companies in 23 countries across North America, Europe and Asia; the matrix presents five types of decision making and six types of governance, and each of its cells shows which type of decision making is done by which type of governance. Its framework suggests that clarification is needed on the identity of the decision-maker (Archetype) and the problem solving (Decision) in order to manage and utilize IT more effectively. Archetypes are largely divided into six: Business Monarchy, IT Monarchy, Feudal, Federal, IT Duopoly, and Anarchy. Decision types are largely divided into five: IT Principles, IT Architecture, IT Infrastructure, Business Application Needs and IT Investment. The relevant definitions are presented in Tables 2 and 3, while IT Governance One Page Matrix is depicted by Fig. 2. Based on these components, new Archetypes and Decisions that are customized for national defense R&D Based are covered in the next section.

For national defense R&D, the Decisions are largely divided into R&D Principles, R&D Architecture, R&D Infrastructure, Business Application Needs and R&D Investment. The Archetypes are divided into National R&D Committee Monarchy, Defense Agency Monarchy, Federal, Defense Industries Monarchy and Anarchy. Based on the abovementioned categorization, Fig. 3 presents the Defense R&D governance matrix. The archetype of National R&D Governance is placed in models according to the degree of governance centrality. Decisions are located according to the country's influence of global dependency. Through the presentation of research model based on this arrangement, the importance of both endogenous factors and exogenous factors such as international relations are emphasized and expressed.

This research aims to identify the appropriate type of governance needed per type of decision-making by the national defensive technological sector, within the digital transformation environment, in which efficient program management and budget execution, as well as procurement of core technology are emphasized. Among the Archetypes presented in the suggested framework, a National R&D Committee Monarchy represents the form in which the highest level of R&D committee on national-level or a corresponsive group leads the effort. In a Defense Agency Monarchy, a national institution tasked with the acquisition of defensive technology or a corresponsive group leads the effort. In a Federal system, a national institution tasked with the acquisition of defensive technology and the national defense industries share the same amount of authority. In a Defense Industries Monarchy, the national defense industries lead the decision making and the projects itself. Lastly, in Anarchy, contractors or colleges and public-private research institutions lead the effort.

The decision-making types are largely divided into five categories. First of all, National Defense R&D Principles refer to a process by which comprehensive directives of the highest national level regarding the method of utilizing resources in and outside the country; managing budget, infrastructure and resources; and supporting an efficient national defense R&D acquisition model. Second, R&D Architecture refers to a process by which decisions on how to compose data, application, infrastructure and Technology Readiness Level (TRL) are made in terms of policy, organizational relation, technicality and methodology, so as to achieve acquisition, technological standardization and integration. Third, R&D Infrastructure refers to a process and methodology and by which relevant foundational infrastructures critical to the enhancement and development of national defense R&D capability are prepared and materialized; this also includes the process of guaranteeing the quality of service that meets the requirements through appropriate budget distribution. Fourth, Business Application Needs refers to a process and methodology by which technology, products and systems necessary to national defense R&D are secured; this includes identifying the business requirements for purchased or internally developed application and a plan to make creative business implementation. Finally, R&D Research refers to a phase during which a decision is made and then approved on how much will be invested into tasks and projects; this is also where the priority, desired effects, level of acquired technology and investment scale are determined.

Archetype / Decision	Business Monarchy	IT Monarchy	Feudal	Federal	IT Duopoly	Anarchy
IT Principles						
IT Architecture						
IT Infrastructure						
Biz Application Needs						
IT Investment						

Fig. 2. IT governance one page matrix.

Table 3
Description of decisions in IT governance matrix.

Decision	Description
IT Principles	High level description on how IT is to be used for business, what ideal operational model is to be adopted for corporation, how the model is to be supported and funded.
IT Architecture	Portrayal of the constitution of data, application and infrastructure, which are required for technological and commercial standardization and integration, as a form of policy, relational and technical choice.
IT Infrastructure	Methods by which foundational services are provided to corporation for its IT capability and usage, an appropriate scale of investment is made at an appropriate time, in order to secure an appropriate quality of service.
Biz Application Needs	Business requirements, technical creativity and compliance to principle. Regarding purchased or internally developed IT application
IT Investment	Phase during which a decision is made/approved regarding the amount of investment on the IT assignment, and on what priority, portfolio and investment scale should be set

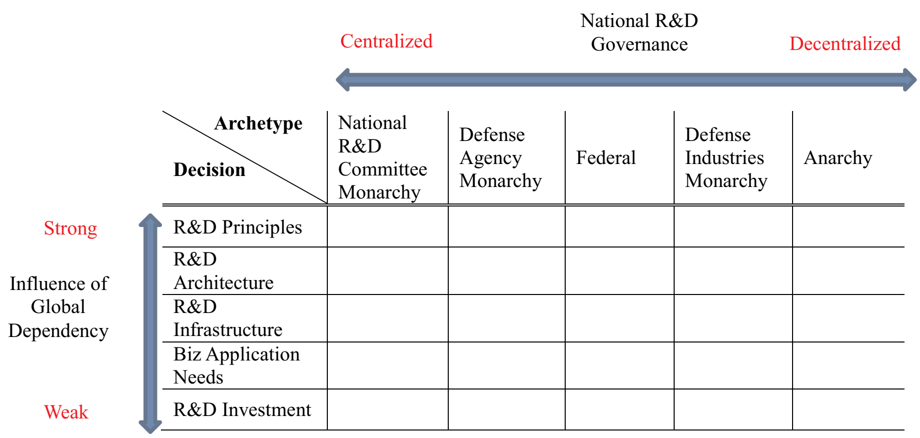

Fig. 3. Defense R&D governance matrix.

4. Method

This section makes a suggestion on the appropriate type of governance in accordance with each decision type, based on the above-mentioned R&D governance matrix. The research was conducted through expert Delphi. It was assessed that appropriate governance type may differ per scale of a particular national defense R&D project; therefore, projects were divided into two types, “defense R&D" and “weapons systems acquisition” and experts were consulted throughout the research.

4.1. Delphi process

The term “Delphi” is derived from the ancient city where the Temple of Apollo was located; according to Greek Mythology, the future was foretold and oracle given from this place. “Delphi” as a method can be regarded as a process by which insight from various experts on a subject matter is compiled and organized to predict the future (Chakravarti et al., 1998; Ludwig, 1997). This methodology was developed by Rand Corporation during the 1950s in an attempt to eliminate limitations from face-to-face discussions and solve urgent security matters of the Cold War era; recently, it is being spotlighted as a way of forecasting the future, as well as solving various issues in the society (Dalkey and Helmer, 1963). The Delphi method is useful and rather simple when executing during a research. It can also be used to estimate conflicts among interest groups or as an arbitration device when accommodating opinions from many persons. In other words, it forms a pool of experts to solve problems that require agreements among interest groups. The Delphi method prefers a panel of experts, rather than a single expert, because it operates based on a basic assumption that “two's assessment is more accurate than one's.”

The Delphi method uses statistical knowledge to identify the right estimation, based on the assumption that an estimate by a panel has a higher chance of encompassing appropriate solutions and strategies. The statistical methods used to guarantee the legitimacy of the Delphi results are largely Content Validity, Reliability and Stability. First, Content Validity is analyzed using Lawshe's content validity ratio (CVR) (Lawshe, 1975). A CVR presents a minimum value according to the number of experts in a panel, which the result must meet or exceed to have legitimacy. Second, Reliability is related to the matter of generalizing the result; it can be estimated in generalizability coefficient and uses the same calculative method as Cronbach alpha coefficient. Lastly, Stability refers to the consistency of responses given by panelists during the repetitive survey process and can be calculated in coefficient of variation. If the coefficient of variation is below 0.5, there is no need for an additional survey. If it is between 0.5 and 0.8, the result is considered “relatively stable.” If it is over 0.8, an additional survey is needed.

Generally, the Delphi method is divided into three types: consensus Delphi, normative Delphi and policy Delphi. The consensus Delphi is based on Locke's empirical science, fit for well-defined problems that allow panelists to come to an agreement. The normative Delphi is based on Kant's practical philosophy, fit for suggesting an alternative rather than coming to an agreement (Yousuf, 2007). The policy Delphi is based on Hegel's philosophy, constructed in such a way so that there are only supporters and opposers who can agree or disagree on various policy alternatives, without the presence of experts (Yousuf, 2007). This research used the normative Delphi, as its primary goal is to find an appropriate alternative that fits the appropriate type in terms of establishing R&D governance on a national level. The description of the procedure and samples are presented in the following section.

4.2. Analytical procedure and sample

The Delphi analysis was conducted largely in two phases. First, National Defense R&D governance matrix's validity was confirmed by surveying experts on the legitimacy and practicality of the framework that was presented in Section 3. Then, various opinions on appropriate

Table 4
Demographic profile of Delphi expert panel.

Category	Item	Number (%)
Gender	Male	15 (100%)
	Female	0 (0%)
	Total	15 (100%)
Age	30–39	2 (13.33%)
	40–49	6 (40.00%)
	50–59	3 (20.00%)
	Over 60	4 (26.67%)
	Total	15 (100%)
Job experience in defense R&D	Under 5 years	0 (0%)
	5–10 Years	0 (0%)
	10–15 Years	3 (20.00%)
	Over 15 Years	12(80.00%)
	Total	15 (100%)
Category	Item	Number (%)
Academic background	Business	3 (20.00%)
	Engineering	8 (53.33%)
	Science	1 (6.67%)
	Others	3 (20.00%)
	Total	15 (100%)
Academic degree	Bachelors	5 (33.33%)
	Masters	6 (40.00%)
	Doctoral degree	4 (26.66%)
	Total	15 (100%)
Affiliation	Government	5 (33.33%)
	Domestic Corp.	5 (33.33%)
	Overseas Corp.	5 (33.33%)
	Total	15 (100%)

governance Archetypes per decision type were gathered through the use of ranking survey to be analyzed further. The Delphi survey for the pool of experts was conducted from June to July 2018. In order to accumulate perspectives from a variety of experts, three categories of experts were to form the pool of experts: government organization, domestic defense contractor and overseas defense contractor. In general, foreign companies were included as participants in the research, because they are active participants in their respective national defense R&D, except for those in a few major defense advanced countries. The demographic profiles of the participating experts are presented in Table 4.

The demographic characteristics of the survey participants are as follows. 100% of the 15 participants were males, most likely due to the subject matter's unique trait. As for the job experience in Defense R&D, all 15 had more than 10 years of career. Five were from a government organization and national research institutions, five were from domestic contractors and five were from foreign contractors. The rationale for including experts from foreign contractors is that latecomer countries usually have high dependency on major foreign defense contractors in terms of R&D.

4.3. Results

The Delphi survey had ranking questions that required the respondents to rank the governance Archetypes from 1st place to fifth place in accordance with their appropriateness. The survey covered two areas: R&D and weapons systems. The reason for distinguishing the two was to examine whether or not the scale of R&D projects affects the respondents' ranking of decision-making type as well as governance type and to analyze any discrepancies that are observed. As shown in Fig. 4 and Fig. 5, the following Decision Rule was made to draw out the most appropriate scenario based on the findings from the survey.

Step 1: If a Decision type's average rank point is 1.8 or lower, select the Archetype of that Decision type.

Step 2: If none of the Decision types meets the conditions for Step 1, filter out decision types with the average rank point of 2.5 or lower, and select the Archetype of the number 1 ranked decision type.

Step 3: If none of the Decision types meets the conditions for Step 1 nor Step 2, redo the survey.

Based on the Decision Rule, four scenarios were deduced from the defense R&D program of the survey, in regards to governance Archetype per Decision.

1) *R&D Principle [National R&D Committee Monarchy], R&D Architecture [Defense Agency Monarchy], R&D Infrastructure [Defense Agency Monarchy], Biz Application Needs [Defense Agency Monarchy] & R&D Investment [National R&D Committee Monarchy]*
2) *R&D Principle [National R&D Committee Monarchy], R&D Architecture [Defense Agency Monarchy], R&D Infrastructure [Defense Agency Monarchy], Biz Application Needs [Defense Agency Monarchy] & R&D Investment [Defense Agency Monarchy]*
3) *R&D Principle [Defense Agency Monarchy], R&D Architecture [Defense Agency Monarchy], R&D Infrastructure [Defense Agency Monarchy], Biz Application Needs [Defense Agency Monarchy] & R&D Investment [National R&D Committee Monarchy]*
4) *R&D Principle [Defense Agency Monarchy], R&D Architecture [Defense Agency Monarchy], R&D Infrastructure [Defense Agency Monarchy], Biz Application Needs [Defense Agency Monarchy] & R&D Investment [Defense Agency Monarchy]*

Archetype / Decision	National R&D Committee Monarchy	Defense Agency Monarchy	Federal	Defense Industries Monarchy	Anarchy
R&D Principles	1 (1.60)	2 (1.73)	3 (2.80)	4 (3.87)	5 (5.00)
R&D Architecture	3 (2.40)	1 (2.07)	2 (2.33)	4 (3.33)	5 (4.93)
R&D Infrastructure	2 (2.53)	1 (2.07)	2 (2.53)	4 (3.27)	5 (4.00)
Biz Application Needs	4 (3.60)	1 (2.40)	3 (2.73)	2 (2.47)	5 (4.00)
R&D Investment	1 (2.07)	1 (2.07)	3 (2.60)	4 (3.47)	5 (4.80)

*Rank (Average rank point)
- Sample size: 15
- Basic and Applied Research, Advanced Technology development in the core R&D program

Fig. 4. Defense R&D survey.

Archetype / Decision	National R&D Committee Monarchy	Defense Agency Monarchy	Federal	Defense Industries Monarchy	Anarchy
R&D Principles	1 (1.60)	2 (2.07)	3 (2.73)	4 (3.67)	5 (4.93)
R&D Architecture	1 (1.73)	2 (1.93)	3 (2.80)	4 (3.67)	5 (4.87)
R&D Infrastructure	2 (2.40)	1 (2.13)	3 (2.53)	4 (3.27)	5 (4.67)
Biz Application Needs	4 (3.33)	1 (2.27)	3 (2.87)	1 (2.27)	5 (4.27)
R&D Investment	2 (2.33)	1 (1.87)	3 (2.67)	4 (3.33)	5 (4.80)

*Rank (Average rank point)
- Sample size: 15
- Over $50M or total program costs of over $100M

Fig. 5. Weapons systems acquisition of defense R&D survey.

Based on the Decision Rule, two scenarios were deduced from weapons systems acquisition of Defense R&D Survey, in regards to governance Archetype per Decision.

1) *R&D Principle [National R&D Committee Monarchy], R&D Architecture [National R&D Committee Monarchy], R&D Infrastructure [Defense Agency Monarchy], Biz Application Needs [Defense Agency Monarchy] & R&D Investment [Defense Agency Monarchy]*
2) *R&D Principle [National R&D Committee Monarchy], R&D Architecture [National R&D Committee Monarchy], R&D Infrastructure [Defense Agency Monarchy], Biz Application Needs [Defense Industry Monarchy] & R&D Investment [Defense Agency Monarchy]*

5. Discussion

The research subject regarding the national level R&D governance mainly covered the concept of partnership among participants and governance network. In other words, its idea of R&D governance pertained to the cooperation among participants of national defense R&D and relations among mutually dependent organizations. However, it was rather limited in its suggestion of a practical guideline that can be used for designing an actual country's R&D governance. It especially lacked the analytical frame for latecomer states. Along similar lines, this research newly presents a two-dimensional National Defense R&D governance matrix and aims to present an appropriate Archetype for governance per decision-making type in national defense R&D. This research contributes to the academia in a sense that it presents elements pertaining to national defense R&D governance in a systematic manner and has designed actual governance in a format that can be easily applied.

The governance with the most optimal combination of the Decision types (R&D Principles, R&D Architecture, R&D Infrastructure, Business Application Needs, R&D Investment) and the Archetypes (National R&D Committee Monarchy, Defense Agency Monarchy, Federal, Defense Industries Monarchy) must be reflected on national defense R&D programs and weapons systems acquisition procedures, in accordance with the scale and budget of a given program. This can be applied through various means to benefit national defense R&D and weapons system-related projects in different countries. If the party involved has a clear understanding of the national defense R&D governance needed to satisfy the requirements of the acquisition entity, which is the end-user, and the resulting decision, it should be able to consider, review and reflect all the elements that must be taken into account through the suggested framework, from the very initial phase. Of note, as it is shown in Section 4.3, the Decision type regarding the most important element, National Defense R&D Principles (a process by which comprehensive directives of the highest national level regarding the method of utilizing resources in and outside the country; managing budget, infrastructure and resources; and supporting an efficient national defense R&D acquisition model), matches up best with National R&D Committee Monarchy (the form in which the highest level of R&D committee on national-level or a corresponsive group leads the effort). The policy implications and challenges that can be deduced from the aforementioned findings are as follows.

First, there must be a structure of governance that emphasizes policy coordination and organic integration. If it is possible to establish such a structure, in which cooperation among specialized governmental agencies and departments, as well as efficiency, can be sufficiently reviewed from the initial planning phase of a project, national defense R&D as a whole will enjoy increased higher intra-governmental efficiency by minimizing redundant investment in similar/overlapping technology and facilitating reciprocity. This should further maximize the efficiency in risk identification, sectorial synergy and project management, as problems expected during every phase of R&D and core elements that accompany them are brought to light for review prior to the start of a project. Previous researches and practices were limited in a sense that they were heavily focused on the decision-making bodies, policy manuals and standardized work procedures of each independent office under the Ministry of Defense. From this point on, there must be a continuation of research and case-studies on the intra-governmental cooperation-based decision-making process, as well as on apologetics for its necessity to the current environment, so that integrative technology advancement takes place on a national level. Up to this point, national defense R&D was centered around maintaining and enhancing the national security and military prowess; the future market indicate that it must go beyond its domain of security and diplomacy to take its place as a facilitator of economic growth. Such a change requires that governance of innovation and participation be established to strategize and strengthen the coordination and cooperation among offices involved in the high levels of national defense R&D; that relevant consultative organizations be systemized; and that organizational culture, communication methods, as well as policy execution/assessment phases, all be institutionalized.

Second, a noteworthy detail in the R&D portion of national defense R&D is that R&D Principles and R&D Investment are favorably matched with National R&D Committee Monarchy and Defense Agency Monarchy, in which a national institution tasked with the acquisition of defensive technology or a corresponsive group leads the effort. Acquisition of national defense capabilities is an important field that requires a significant budget and determines the security of the nation. However, due to lack of transparency, dispersed organizational management and insufficiently rational operation of the financial resources in the existing acquisition system, that led to inefficiency and weakening the competitiveness of the defense industry. Acquisition planning, in particular, must be subjected to constant innovation, as it must adjust appropriately to the pace by which technological progress is made, so that the government can nurture its own internal R&D capability, while industrial and academic R&D prowess are applied to national defense.

Budget planning must be supplemented by the review and coordination of financial investment plan for military requirements, so that relevant offices are able to determine the appropriate budget, in accordance with the national fiscal management plan, carry out their acquisition duty. Such efforts should allow a reasonable coordination and management of the scale, overall cost and period throughout the various phases of the program, improving the efficiency in spending and shaping up favorable environments. In terms of the management and analysis of finances, there must be an analytical assessment of program-related elements in order to formulate a plan for budget management for efficient use of the national budget; to manage, control and achieve program objectives per phase; to ensure rational distribution and efficient usage of funds; and to support rational decision-making in the process. This requires a high level of expertise and a national level of cooperative strategy with a consistent policy that points to medium and long-term goals/visions and takes into account global technological cooperation, as well as exportation. In terms of expertise, in particular, there must be a concerted effort to lay down a system that can be reformed flexibly by being receptive to various opinions shared by various participants, on top of the national effort to train more experts in national defense R&D.

Third, a noteworthy detail in the weapons systems portion of national defense R&D is that Business Application Needs (a process and methodology by which technology, products and systems necessary to national defense R&D are secured, and the business requirements for purchased or internally developed application, as well as a plan to make creative business implementation) is favorably matched with Defense Agency Monarchy and Defense Industries Monarchy, in which the national defense industry leads the decision making and the projects itself. Generally, when budget appropriation is being reviewed, one important question asked is on whether the results of the R&D will have a lasting connection with the development of actual weapons systems. Technology or products derived from basic science and applied science are often not implemented at all in a weapons system project; even when they are, the resulting weapons system is inferior to those of advanced countries in terms of the amount of time consumed, technology and quality. In such a case, there may be a discrepancy between the accomplishment and performance. If national defense R&D is led by the defense industry to overcome this problem, long term plans and investment should enhance the technical skills and expertise, which will eventually contribute to the self-reliance of defense industries by exerting positive influences on the localization of core technical skills and equipment components. Such a model is needed, because it can also contribute to the export-competitiveness of the defense industry, if it is able to facilitate international cooperation among defense industry in the form of strategic partnership and joint development of core technology. Most advanced countries have their defense industry lead the weapons systems R&D.

Republic of Korea's T-50 Trainer R&D Project is regarded as a successful development program of the defense industry-driven R&D model. T-50 trainer is a family of South Korean supersonic advanced trainers and light combat aircraft, developed by Korea Aerospace Industries (KAI) with US Lockheed Martin. The T-50 is South Korea's first indigenous supersonic aircraft and one of the world's few supersonic trainers. The most important contributor to the success, both domestically and internationally, is the implementation of a model in which the defense industry drove the R&D effort, while the Republic of Korea Air Force was given the management role; this was the first time such a model was taken up in Korea. In 1995, the Korean government, after weighing the schedules, cost and performance, as well as the will to pursue business, made a decision to adopt the advanced form of program model, that is the defense industry-led R&D, as the most efficient way ahead (Lee and Yoon, 2015). This event has made the developmental model of “Military-managed, Industry-led” a prominent case in which the actual end-user and the manufacturer cooperated with one another for substantive ideas.

Lastly, the abovementioned implications can ultimately be matched with the appropriate governance type for policy adjustment, integration and innovation, by referring to the Archetype suggested in National Defense R&D governance Matrix. It is important that diplomatic and security-related efforts, which include survival in the global market and practical, long-term changes in the policy direction and consultation process among interest groups/offices, be taken into account during the decision-making process of national defense R&D. This is especially true for latecomers in the defense industries. Such countries must produce internationally competitive goods and technology, while formulating a strategy that hits two birds with one stone by maintaining their own security and cultivating their own industry. Such a task will require them to make use of the National Defense R&D governance matrix to choose the most efficient type of governance that fits their own circumstances. Latecomer governments should play a significant role in innovation (Hobday et al., 2000). In addition, they will need to plan a long-term strategy to pursue active cooperation with advanced countries to research and develop weapon systems that their own acquisition entities require.

6. Limitations and further study

Although this research provides various academic and policy implications, it is still limited in terms methodology or generalization. First and foremost, every government official or domestic contractor who participated in the survey was Korean, meaning the research lacks insight regarding cultural differences or administrative traits exhibited by different countries. One area of improvement that can be made for future research includes comparative research among countries or an expansion of the expert pool, both of which will enhance the robustness and objectivity of the research findings. Second, decision science method, such as the AHP method, should be utilized in tandem with the Delphi method, which was used for this research; combined with the governance matrix presented by this research, the findings can be deduced in more diverse ways and be applied strategically. Lastly, this research failed to reflect that emerging countries have different national R&D types and strategies that are in accordance with their level of economic growth; a more in-depth research is needed to indicate more accurate findings that consider the differing levels of development among countries.

References

Arnold, E., 2004. Evaluating research and innovation policy: a systems world needs systems evaluations. Res. Eval. 13 (1), 3–17.

Bloch, C., 2007. Assessing recent developments in innovation measurement: the third edition of the Oslo manual. Sci. Public Policy 34 (1), 23–34.

Boekholt, P., Arnold, E., Deiaco, E., McKibbin, S., Simmonds, P., Stroya, J., de la Mothe, J., 2002. The Governance of Research and Innovation. An International Comparative Study Country Reports. Technopolis, Amsterdam.

Bontis, N., 2001. Assessing knowledge assets: a review of the models used to measure intellectual capital. Int. J. Manag. Rev. 3 (1), 41–60.

Burmaoglu, S., Sarıtas, O., 2017. Changing characteristics of warfare and the future of Military R&D. Technol. Forecast. Soc. Chang. 116, 151–161.

Chakravarti, A.K., Vasanta, B., Krishnan, A.S.A., Dubash, R.K., 1998. Modified Delphi methodology for technology forecasting case study of electronics and information technology in India. Technol. Forecast. Soc. Chang. 58 (1–2), 155–165.

Cho, Y., Yoon, S.P., Kim, K.S., 2016. An industrial technology roadmap for supporting public R&D planning. Technol. Forecast. Soc. Chang. 107, 1–12.

Christensen, A.M., 1989. Military Research and Development. Technological Change and Civilian Economic Growth. vol. No.2 PRIO Report, Oslo.

Coccia, M., 2018. A theory of the general causes of long waves: war, general purpose technologies, and economic change. Technol. Forecast. Soc. Chang. 128, 287–295.

Dalkey, N., Helmer, O., 1963. An experimental application of the Delphi method to the use of experts. Manag. Sci. 9 (3), 458–467.

DARPA, 2016. Innovation at DARPA - Defense Advanced Research Projects Agency. Online source. https://www.darpa.mil/attachments/DARPA_Innovation_2016.pdf.

Davies, A., Hobday, M., 2005. The Business of Projects: Managing Innovation in Complex Products and Systems. Cambridge University Press.

Desli, E., Gkoulgkoutsika, A., Katrakilidis, C., 2017. Investigating the dynamic interaction between military spending and economic growth. Rev. Dev. Econ. 21 (3), 511–526.

Drucker, P., 2014. Innovation and Entrepreneurship. Routledge.

Etzkowitz, H., Ranga, M., 2015. Triple Helix systems: An analytical framework for innovation policy and practice in the knowledge society. In: Entrepreneurship and Knowledge Exchange. Routledge, pp. 117–158.

Figueiredo, P., Gutenberg, S., Sbragia, R., 2007. Risk-sharing partnerships with suppliers: The case of Embraer. In: Challenges in the Management of new Technologies, pp. 241–262.

Fox, J.R., Field, J.L., 1988. The Defense Management Challenge: Weapons Acquisition. Harvard Business School Press, Boston, pp. 38.

Godoe, H., 2000. Innovation regimes, R&D and radical innovations in telecommunications. Res. Policy 29 (9), 1033–1046.

Guo, D., Guo, Y., Jiang, K., 2018. Governance and effects of public R&D subsidies: evidence from China. Technovation 74, 18–31.

Hendrickson, J.R., Salter, A.W., Albrecht, B.C., 2018. Preventing plunder: Military technology, capital accumulation, and economic growth. J. Macroecon. 58, 154–173.

Henriksen, L.F., Ponte, S., 2018. Public orchestration, social networks, and transnational environmental governance: lessons from the aviation industry. Regulat. Govern. 12 (1), 23–45.

Hobday, M., Rush, H., Joe, T., 2000. Innovation in complex products and systems. Res. Policy 29 (7-8), 793–804.

Johnson, W.H., 2008. Roles, resources and benefits of intermediate organizations supporting triple helix collaborative R&D: the case of Precarn. Technovation 28 (8), 495–505.

Kaplan, R.S., Kaplan, R.E., Norton, D.P., Norton, D.P., Davenport, T.H., 2004. Strategy Maps: Converting Intangible Assets into Tangible Outcomes. Harvard Business Press.

Karabag, S.F., Berggren, C., 2016. International R&D collaboration in high tech: The challenges of jet fighter development partnerships in emerging economies. In: Handbook of Research on Driving Competitive Advantage through Sustainable, Lean, and Disruptive Innovation. IGI Global, pp. 455–472.

Kollias, C., Paleologou, S.M., 2017. Military spending, economic growth and investment: a disaggregated analysis by income group. Empir. Econ. 1–24.

Kuhlmann, S., Edler, J., 2003. Scenarios of technology and innovation policies in Europe: Investigating future governance. Technol. Forecast. Soc. Chang. 70 (7), 619–637.

Lawshe, C.H., 1975. A quantitative approach to content validity. Pers. Psychol. 28 (4), 563–575.

Lee, J.J., Yoon, H., 2015. A comparative study of technological learning and organizational capability development in complex products systems: distinctive paths of three latecomers in military aircraft industry. Res. Policy 44 (7), 1296–1313.

Lee, Y., Fong, E., 2018. True impact of hidden knowledge on the R&D governance. In: Academy of Management Proceedings. vol. 2018, No. 1. Academy of Management, Briarcliff Manor, NY 10510, pp. 12143.

Li, P.P., 2010. Toward a learning-based view of internationalization: the accelerated trajectories of cross-border learning for latecomers. J. Int. Manag. 16 (1), 43–59.

Ludwig, B., 1997. Predicting the future: have you considered using the Delphi methodology. J. Ext. 35 (5), 1–4.

Malik, T.H., 2018. Defence investment and the transformation national science and technology: a perspective on the exploitation of high technology. Technol. Forecast. Soc. Chang. 127, 199–208.

Moretti, E., Steinwender, C., Van Reenen, J., 2014. The Intellectual Spoils of War? Defense R&D, Productivity and Spillovers. Working Paper. London School of Economics.

Mowery, D.C., 2010. Military R&D and innovation. In: Handbook of the Economics of Innovation. vol. 2. pp. 1219–1256 (North-Holland).

Neuman, S.G., 2006. Defense industries and global dependency. Orbis 50 (3), 429–451.

Neuman, S.G., 2010. Power, influence, and hierarchy: defense industries in a unipolar world. Defence Peace Econ. 21 (1), 105–134.

Nill, J., Kemp, R., 2009. Evolutionary approaches for sustainable innovation policies: from niche to paradigm? Res. Policy 38 (4), 668–680.

Plummer, L.A., Gilbert, B.A., 2015. The effect of defense agency funding of university research on regional new venture creation. Strateg. Entrep. J. 9 (2), 136–152.

Rotblat, J., Reppy, J., Avduyevsky, V., Holdren, J. (Eds.), 2016. Conversion of Military R& D. Springer.

Stowsky, J., 2004. Secrets to shield or share? New dilemmas for military R&D policy in the digital age. Res. Policy 33 (2), 257–269.

Trebelicock, C., 1969. "Spin-off" in the British economy: armaments and industry. Econ. Hist. Rev. 22 (2), 474–490.

Weill, P., & Ross, J. W. (2004). It Governance on One Page. MIT Sloan Working Paper No. 4517–04; CIS Research Working Paper No. 349. Available at SSRN: https://ssrn.com/abstract=664612

Yousuf, M.I., 2007. Using experts' opinions through Delphi technique. Pract. Assess. Res. Eval. 12 (4), 1–8.

Mr. Jun Gon Lee is doctoral candidate at a Seoul Business School, aSSIST. As master degree, he studied in business administration and got Executive MBA degree at Aalto University. For a number of years he worked mainly in the field of aviation and defense industry. His research interest focuses on strategic R&D management and governance. e-mail: jayjglee@gmail.com, Tel: +82-70-7012-2727

Prof. Min Jae Park is academic director of Executive MBA Program of Aalto University, Seoul and an assistant professor in Seoul Business School, aSSIST. He obtained a Ph.D. degree in the Business and Technology Management at the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea. His research interests include R&D management, innovation by technology like IoT, and data mining for public sector. His research articles have been published in Government Information Quarterly, Public Management Review, International Journal of Information Management, Telecommunications Policy, Energy Policy and *etc*. e-mail: mjpark2@assist.ac.kr, Tel +82-70-7012-2727