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Transition and Development of Science and Technology Policies in North Korea:

A Study on the Industrial Revolution of the New Century

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Abstract

North Korea has expended considerable effort in pursuing its goal of the Industrial Revolution of the New Century (IRNC), which is known as North Korea's latest science and technology (S&T) innovation at the same time economic development strategy. Despite its dire economic conditions, exacerbated by the recent sanctions, the country has expended considerable amounts of resources and efforts in pursuing its goal of leapfrogging through the IRNC. However, existing biases and high standards of S&T evaluation towards this lower-middle-income (LMI) state led its S&T to be considered as rather obsolete. Is North Korea's S&T too obsolete to be used as a means for economic development? This thesis explores the transition and development of North Korea's S&T policy and its capability from Kim Jong-il's S&T-oriented policy to Kim Jong-un's IRNC. It aims to explain the characteristics of the IRNC compared to the previous regime's S&T policy and how certain changes have resulted in North Korea's current S&T development. Thereby, the paper argues that the current regime's S&T policy via the IRNC has allowed the acceleration of innovation development lacked in the previous regime. It also argues that North Korea's S&T innovations since Kim Jong-un's regime do not fall behind those of other countries at similar stages of their industrial development. The current government's innovations clearly show that this time, North Korea has the potential to leapfrog. Yet, it also notes that the current regime's persistent pursuit of nuclear weapons and isolation from the international scene will limit its potential to achieve further economic growth as a socialist economic powerhouse.

Keyword : North Korea, Kim Jong-un, the Industrial Revolution of the New Century, science and technology, economic development

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I. Introduction

Since Klaus Schwab announced the era of the Fourth Industrial Revolution during the 2016 Davos World Economic Forum, attention to the idea of industry 4.0[1] and the new wave of the industrial revolution has only grown. Even before 2016, many advanced industrial countries had already been investing heavily in research and development (R&D) in this new sector, featuring cooperation between governmental, civil, and academic organizations, such as the German-led idea of industry 4.0 in 2011 and the U.S.-led concept of the Internet of Things (IoT) gained currency in the late 2000s. Interestingly, North Korea was also working in these areas earlier than most developing countries. Despite its dire economic conditions, exacerbated by the recent sanctions, North Korea has expended considerable amounts of resources and efforts in pursuing its goal of leapfrogging through the Industrial Revolution of the New Century (IRNC), which entails both North Korea's latest Science and technology (S&T) innovation and economic development strategy. Accordingly, North Korea's S&T policy under the IRNC has received the scholarly attention that has identified North Korean technological advancements and its limitations since 2012 (Park, 2019; Lee, 2019; Kim, 2018;

[1] Industry 4.0 refers to the digital transformation of manufacturing or production system and value creation process where the Internet of Things (IoT) is integrated into traditional manufacturing or industrial practices.

Moon, 2019; Ku, 2017; Lim, 2019).

Understanding North Korea's progress of S&T policy and its innovation capability is imperative as they are closely linked to the country's economic development and liberalization. However, only a few research deal with the IRNC as an S&T policy, and even these small number of studies that are more focused on introducing either Kim Jong-il or Kim Jong-un's S&T policies neglect policy comparison between the two Kims and North Korea's S&T capability. As the expectations and significance of S&T innovation increase both internally and externally, North Korea will inevitably find itself facing liberalization since sufficiently upgrading S&T can be only be achieved when it is accompanied by reform and "opening up," including denuclearization. Without reform and openness, North Korea would simply focus on developing nuclear, missile, and hacking-related technologies. The current move by the North Korean government, however, shows that this hermit state is trying to enhance its overall level of S&T capability – including S&T for military purposes. Thus, it can be inferred that the country is willing to adopt a certain level of reform and opening up if it deems necessary for bolstering its S&T innovations, but only until these liberalizations begin to threaten the current regime's stability.

Meanwhile, many media reports and prior studies by South Korean scholars have evaluated North Korea's science and technology (S&T) are rather obsolete (Ku, 2017; Kim, 2016; Ryu, 2018; Lee, 2018), comparing the

developments they have observed with those of South Korea. However, is North Korea's S&T too obsolete to be used as a means for economic development? Many prejudices against North Korea exist today, with titles such as the Hermit Kingdom, a member of the Axis of Evil, and a destitute country (Levkowitz, 2007; Choi, 2010; Choi 2018). While these prejudices may not be groundless, they could also prevent an objective analysis of the country. For example, according to the Bank of Korea and the 2018 report of the World Bank, North Korea's gross national income (GNI) per capita was $1,157, comparable to those of the Kyrgyz Republic, Cambodia, Bhutan, and Lao PDR, at $1,220, $1,390, $2,970, and $2,450, respectively. North Korea is ranked as a lower-middle-income (LMI) state,[2] featuring stifled industrial development compared to South Korea, whose GNI per capita in 2018 was 23 times that of North Korea's. Due to this gap in both income and industrial level between the two countries, taking a South Korean perspective on North Korea's S&T is likely to lead to an underestimation of its level of innovation. It is only fair to analyze and evaluate North Korea's S&T capabilities by comparing them to those of countries with similar levels of income and industrial capabilities.

In this respect, this thesis explores the transition and development of North

[2] According to the World Bank's 2018 standards, countries with a per capita GNI of less than $1,025 are considered low-income states, those with less than $3,995 are lower-middle-income states, and those with less than $12,375 are upper-middle-income states. High-income countries, including South Korea, are considered to have a per capita income of over $12,376. North Korea is considered to be a low-income country by the World Bank, but based on the official standards, North Korea would be considered as an LMI state. Thus, based on the 2018 World Bank standards, North Korea is considered to be an LMI state.

Korea's S&T policy and its capability from Kim Jong-il's S&T-oriented policy to Kim Jong-un's IRNC. It aims to explain the characteristics of IRNC compared to the previous regime's S&T policy and how certain changes have resulted in North Korea's current S&T development. Thereby, the paper argues that the current regime's S&T policy via the IRNC has allowed the acceleration of innovation development lacked in the previous regime. It also argues that North Korea's S&T innovations since Kim Jong-un's regime do not fall behind those of other countries at similar stages of their industrial development. The current government's innovations clearly show that North Korea has the potential to leapfrog. In addition, the paper analyzes North Korea's S&T policies and how its current and future innovation outputs could affect North Korea's reform, the chances of cooperation between the North and the South, and possibly denuclearization of the Korean Peninsula.

Whether North Korea will develop a powerful knowledge economy or remain stagnant depends on Kim Jong-un's decision on denuclearization. Although the effects of the UN sanctions on North Korea's economy cannot be accurately measured, the lack of delivery of energy resources, limited foreign direct investment, reduced S&T-related research funding, and lack of cooperation with other states certainly hinder North Korea's potential to achieve economic growth through the IRNC. To develop the IRNC to the point of transforming North Korea into a truly "strong socialist powerhouse," it is crucial to achieving accelerated

marketization and technological cooperation between countries, which can only be achieved when sanctions are lifted.

In addition to pre-existing literature, the research findings are mainly based on an analysis of the content of decision papers by Workers' Party of Korea, North Korea's official media such as Rodong Sinmun, Korean Central News Agency (KCNA) and Naenara, and North Korean Economic Journal articles. For the evaluation of North Korean innovation outputs, NK tech by KISTI and Web of Science are utilized as the main sources to collect scientific articles written by North Korean scientists and published in international journals. The paper also refers to *DPRK Official Journal of Invention* from 1999 to 2018 as the main source to analyze North Korea's patent output. Data provided by the World Bank, World Intellectual Property Organization (WIPO), and the Korea Intellectual Property Office (KIPO) are used for a more thorough and accurate investigation.

The composition of this thesis is as follows: the following section entails a brief review of relevant literature, followed by the provision of the analytical framework of the study. The next section describes the S&T policy of different regimes and investigates the similarities and any changes to the policy. Chapter four analyzes the innovation output of the country, focusing on its S&T publication to international journals and patent registration and application not only by different regimes but also with other LMI states. The conclusion entails a short discussion of some key implications of the IRNC for North Korea's economic

reform and denuclearization, along with an evaluation of whether the IRNC will indeed be North Korea's key to leapfrogging.

II. Literature Review

1. North Korea's Current Economic Status

North Korea's current economic status is more dynamic than ever. Although its bottom-up marketization began after the Arduous March concept during Kim Jong-il's reign, the government's reluctant consent to marketization and abrupt currency reform resulted in economic fluctuations until the late 2000s. Ever since Kim Jong-un took his father's place, however, North Korea's economy has been characterized by a stable dual structure, where central planning and the market on the one hand and the state and private economy on the other all coexist with stable economic growth.

According to data provided by the Bank of Korea (South Korea's central bank), North Korea's growth rate under the Kim Jong-il regime fluctuated heavily, ranging between -7.1% and 3.8% growth (in 1999, a 6.1% growth was reported, but was an exception), with generally a negative growth rate.[3] Currently, North

[3] The exact growth rate of North Korea's economy cannot be accurately measured as the country blocks any of its economic statistics and information. Thus, statistics provided by international organizations or reliable research institutes differ significantly. Many North Korea studies scholars

Korea's economic growth rate has stabilized to about a 1% annual rate on average, gradually increasing during Kim Jong-un's rule, although in early 2017, the economy fell by -3.5% due to intensified economic sanctions ratified under the UN Security Council. North Korea's current GNI and GNI per capita show signs of a steady increase. The country's GNI per capita surpassed the $1,025 mark, up to a record $1,086 in 2011, meaning that, based on the World Bank's standards, North Korea could be classified as an LMI country.

North Korea is no longer destitute. Its food supply has shown remarkable improvement, with signs of continued economic growth. Famine no longer affects even the poorest farmers (Lankov, 2017). Inequality does exist, but its causes seem different from those of previous regimes. For example, provincial inequality and class inequality following famine is not caused by agricultural self-sufficiency, but by the state's coercive industrialization, which seeks greater economic and technological development. However, such inequality can be compensated partially by market opportunities (Smith, 2009).

The main difference between the approach of Kim Jong-un and that of his two predecessors lies in the government's attitude toward marketization. Markets are the most important factors in the twenty-first-century North Korean economy.

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and experts believe that the growth rate provided by the Bank of Korea is underestimated, claiming that the actual growth rate is 1–2 percent or even 3-4 percent higher than the bank's initial claims (Yang and Chang, 2017; Lankov, 2017; Kim, 2019).

Donju, North Korean market operators and private businessmen, are no longer targets of harassment (Lankov, 2017). During the Kim Jong-un era, cooperation between the official government and private market forces is encouraged to promote prosperity. According to the satellite imagery provided by Curtis Melvin, a researcher at Johns Hopkins University, the number of official markets in North Korea has more than doubled from 200 to 406 between 2010 and late 2015 (Silberstein, 2015; Chosun, 2015).

Kim Jong-un's reformist approach to marketization has led to further attempts to attract foreign capital. This idea is not new, as the Rajin-Sonbong Special Economic Zone (SEZ) was established during his father's rule, but the number of SEZs increased to 25 during the first five years under Kim Jong-un. However, foreign investors are still unwilling to invest in a country that is lacking in institutions that could protect their private property even before the comprehensive international sanctions were brought to bear in 2017. For instance, the Chinese firms Xiyang Group that had built mining facilities and spent $37.1 million on a joint venture experienced significant losses when the North Korean government deported their workers and fully seized their assets in 2012. The owner of the Xiyang Group, Wu, has claimed that their case is just one of the dozens of Chinese enterprises that have suffered from the North Korean authorities (Taylor, 2012). Despite such complaints from many foreign entrepreneurs, Kim Jong-un appears to have enjoyed increased economic outputs thanks to this mild reformist

approach to marketization.

However, North Korea's expansion of trade with China offset the decreased investment by other foreign countries. The scale and nature of foreign relations have been used to pressure the country. Previously, South Korea, the U.S., and Japan hoped to contain North Korea through economic sanctions, such as Japan's trade ban in 2006 and South Korea's suspension of food and fertilizer aid in 2008, and the suspension of the Inter-Korean Economic Cooperation in 2010 (excluding the Kaesong Industrial Complex). These sanctions only contributed to an increase in China-North Korea trade. In the early 2000s, with China, Japan, and South Korea as primary trade partners, the ratio of trade between North Korea and China was similar to that between North Korea and Japan. However, statistics from KOTRA have shown that the rate of trade between North Korea and China has increased, reaching 90% of overall foreign economic relations in 2014, which entails a significance on China. Thanks to the importation of Chinese food and consumer goods, the North Korean standard of living has increased, and market distribution has expanded. China has helped modernize North Korea's state-owned enterprises and infrastructure construction projects, for which North Korea imported machinery, metals, and raw materials from China (Kim, 2019).

The international community hopes that sanctions against North Korea will affect its economy to the point where it is forced to denuclearize, in reality, it does not seem to be economically crippled. This is because the initial sanctions instituted

in 2006 were not sufficiently strong. Until 2015, the sanctions were limited to weapons, military supplies, and certain luxury goods. The 2016 Security Council resolution tightened sanctions to include general exports and imports, finance, and cargo searches but excluded civilians' livelihoods, which prevented any significant impact on North Korea's foreign trade. It was not until 2017 that sanctions finally banned most of North Korea's export goods, joint ventures, and certain imports (electronics, machinery, metal, cars, and so on). North Korea's foreign currency earnings were mostly blocked by the second half of 2017. The economy grew 3.9% in 2016, but that rate dropped to -3.5% for 2017 and -4.1% for 2018. However, smuggling between China and North Korea continued through this period via ship-to-ship transfer or by transfer across an 870-mile border, despite the intensified sanctions. Seeing that North Korea's economic growth recovered in 2019 to 0.4%, the current sanctions appear incapable of fulfilling their mission of curbing Kim's nuclear ambitions.

2. Inter-Korean S&T Cooperation Optimists and North Korean S&T Skeptics

The literature on North Korea's new science and technology policy has primarily focused on its effects on the relationship between the two Koreas rather than giving its background or reporting on its performance. Byun (2016) argues that the IRNC should not be seen as a one-time project by Kim Jong-un. Rather, it follows a theme of his father's and continues his project of establishing a knowledge economy,

indicating that the IRNC will likely persist for an extended period of time. If Kim's regime emphasizes the IRNC, it could potentially enable cooperation with South Korea, particularly in the S&T sector. Lim (2019) contends that North Korea's IRNC offers a new perspective on inter-Korean relations and is an opportunity for cooperation. Here, the success of the Fourth Industrial Revolution is judged to depend to a certain extent on the abilities of economic policy-makers and practitioners. Since industry 4.0 requires a certain standard of labor flexibility, education system, technology, infrastructure, and legal system, North Korea's lack of openness, sharing, and participation may cause the country to face limitations. Lee (2019) notes an exchange of Industry 4.0 knowledge between North and South Korea can be expected, particularly in the agricultural sector, which is less affected by international sanctions. Should the sanctions against the North were lifted, he argues, inter-Korean cooperation in ICT, big data, and semiconductor production may become possible. That is if South Korea's ICT infrastructure and network can be combined with North Korea's human resources, joint research, technological cooperation, and commercialization may be possible in the areas of data analysis, voice recognition, 3D printing, and artificial intelligence (AI). North Korea's abundance in natural resources such as nickel and rare earth elements that are essential components of electronic cars and semiconductors respectively could contribute to the inter-Korean relationship.

Many scholars agree that denuclearization and economic reform are

prerequisites to any inter-Korean cooperation within industry 4.0. Byun and Choi (2012) assert that Kim Jong-un's attempts to turn North Korea into a powerful knowledge economy through the IRNC are done with the intention of promoting economic growth retaining the current political and economic systems of the state. If the IRNC policy presupposes a closed economy and national self-reliance, it will not achieve more than limited economic development. Byun and Choi stress that while the IRNC could alleviate North Korea's condition of "scrimping and saving," doing so could only be achieved through internal economic reform and a new open-door policy. Moon (2019), in the same vein, notes that inter-Korean economic cooperation will only be possible through the North's reforms. Once the door opens, he claims, North Korea will be able to achieve economic growth in an active industry 4.0 cooperation. Lee (2019) on the other hand believes that any cooperation via industry 4.0 will be possible only through peaceful denuclearization.

When evaluating North Korea's S&T innovation, most researchers are pessimistic regarding the level of North Korea's S&T innovation. Ku (2017) is skeptical of North Korea's financial capability to create world-class AI, presenting a comparison between North Korea's Go AI Eunbyul to Alpha Go. Kim (2016) also finds that North Korea's limitations of electrical power, along with large-scale issues with network maintenance, will limit its ability to develop a sustainable S&T information system. In addition, North Korea's isolation limits the potential of its

IRNC, which may lead to poor results. Likewise, Lee and Kim (2015) mention that North Korea's industry 4.0 lacks the ability to self-sustain capabilities and that national policies make it difficult to begin and sustain a virtuous cycle of investment to earn profits.

Many biased reports have been published on North Korea's Fourth Industrial Revolution. A number of news reports in South Korea provoke a sense of rivalry between the two countries and dismiss or deride the North's S&T. The conventional idea of North Korea among the international community as an isolated, desolated, and evil country have affected the media's underestimation of North Korea. For instance, Lee (2016)'s provocative question "South Korea vs North Korea, whose AI technology is superior?" publicly denigrates North Korea's hardware as outdated. Chang's (2016) "Does North Korea research AI? Too little result from too much time" asserts North Korea is backward through a comparison of the two countries' level of technology. Ryu (2018) and Lee (2018) also agree to the preconceived notion of North Korea as a backward economy with statements such as "Can South Korea, a world-class IT powerhouse with a per capita income of nearly $30,000, pursue a "win-win" project in the technology sector through cooperation with North Korea. A project that doesn't involve the development of North Korea's underground resources."

North Korea's IRNC has recently received more scholarly and media attention, especially in South Korea. However, despite this, little research has dealt

with explaining the country's motives and its current condition of S&T as both science and technology and economic strategy. The expectations and significance of North Korea's IRNC are increasing, both internally and externally, and the country finds itself facing the possibility of an accelerated reform of the existing system. I will explain this in detail below.

3. Analytical Framework

Ever since S&T-oriented policy was initiated by Kim Jong-il in the late 1990s, "integration of science and economy" was actively discussed, seeking for economic development by upgrading S&T. Although S&T has been consistently emphasized since liberation, its significance is growing at the fastest rate as is integrated with the economic policy during the Kim Jong-il era. North Korea's notion of science has changed to the scientism that "any adverse condition can be overcome by fostering S&T" (Byun, 2016). Under such circumstances, Kim Jong-il promoted science-oriented policy and argued that a "strong and prosperous nation" (kangsongtaeguk) can be achieved by cutting-edge science and technology. Although North Korea's internal and external crisis became worse than during Kim Il-sung's reign, Kim Jong-il considered there is still a chance not only to overcome hardships but also to strengthen the national economy and defense. He thought S&T was the key to the lead country becoming a socialist powerhouse surrounded by international isolation (Kim, 2000; Byun, 2016).

When it comes to the Kim Jong-un era, the national efforts for economic development are still prioritized, and expect S&T innovation as a key for its leapfrogging. Kim Jong-un at a plenary session in March 2013 declared “building a knowledge economy powerhouse powered by S&T” (KCNA, 2013). In addition, he also stressed the construction of a "science and technology powerhouse" as an “important goal to preemptively occupy in building a socialist powerhouse" during the seventh party congress in 2016. In other words, North Korea considers economic development and S&T development to be key positions in its socialist power initiative. The Kim Jong-un regime's “dual policy of nuclear and economic development,” which aims to overcome political and economic isolation and sanctions by developing science and technology, and strengthening the nation's economic and nuclear deterrence capabilities, has the same logic (Byun, 2016). North Korea's science and technology development not only strengthens its military capabilities through the advancement of nuclear, missile, and hacking-related technologies but also focuses on the practical side of economic improvement by incorporating S&T in various parts of society.

Accordingly, North Korea known as the oldest dictatorial and socialist nation puts regime stability as the top priority. Nevertheless, the country considers at least a minimum level of liberalization and seeks economic development strategy via the advancement of S&T. Despite national efforts to enhance S&T innovations, a number of studies mainly done by south Korean scholars simply assessed North

Korea's S&T as rather obsolete. Along with pervasive prejudices against North Korea, the spread of inter-Korea comparison of S&T capability has worsened the independent but objective analysis of the North's S&T innovation competence. Thus, this paper seeks to purely focus on North Korea's S&T innovation capability itself, and if have to, compare its competence again other countries that have similar income level to the North.

The end of the Second World War opened up the global race in enhancing S&T, especially between highly industrialized countries, and that S&T has become a driving force for economic development. The significance of S&T is growing at the fastest rate thus monitoring and evaluating its performance has become crucial. Indeed, a variety of methodologies to assessing S&T, in other words, innovation outputs has been widely discussed by scholars. However, to some extent, the method of measuring S&T in the right way is still controversial as there is no "correct" way of evaluating it, even if some measures are more likely to be criticized by others (Kennedy, 2015). Therefore, current literature regarding S&T evaluation or cross-country comparison of S&T uses a variety of methods to illustrate the S&T capability of the countries. Some studies even adopt indirect indicators such as foreign trade, labor force, or investment in the R&D-intensive sector as an analytical tool for diagnosing technological performance or trends.

However, the majority of papers related to S&T evaluation refer to the use of scientific publication and patent as an indicator. S&T publication can be

analyzed by using citation indexes provided by the Science Citation Index (SCI) or the Institute for Scientific Information (ISI), or in a more recent version of the ISI's Web of Science. Garfield (1979) emphasized the significance of S&T publication analysis by saying, "if the literature of science reflects the activities of science, a comprehensive, multidisciplinary citation index can provide an interesting view of these activities. This view can shed some useful light on both the structure of science and the process of scientific development." Patent indicators, on the other hand, is a useful tool for measuring the technological performance of countries. S&T considered to be a major driving force of economic development has been widely accepted by many scholars. As illustrating linkage between technological and economic performance is quite complicated, here is where patents come in to link between the two. Francis Narin, Anthony Breitzman, and Patrick Thomas (2004) argued that the technological performance of firms assessed by patent indicators contributes to understanding its relevant impact on stock market value. Eduardo da Motta e Albuquerque (2004) also analyzed the capacity of less developed countries by adopting patent and publication as indicators. He emphasizes that these indicators are effective for characterizing countries' outputs thereby encouraging adequate innovation policies.

More precisely, Scholars who investigate or compare the rising power of China and India's innovation progress adopt relatively traditional S&T innovation indicators such as scientific publications, patent data, and national R&D

expenditure. Earnest Preeg (2008) examined the rapid technological development of China and India where he was impressed with China and India's technological progress by investigating their technology policy, R&D spending, technological related-education, foreign direct investment, and technological innovation. His research specifically used patent data and publications as a tool to measure these two countries' innovation. Preeg (2008) anticipated India is likely to continue its annual growth of 8 to 10 percent, whereas China would shift its export-oriented strategy to domestically-oriented growth with possibly 5 to 7 percent of annual growth. Hu Angang (2011) analyzed China's S&T power into five categories which of each category works as a quantitative indicator. He firstly measured the national capacity of innovation in science by counting on the number of international scientific journals being published. He then adopted the data of China's patent applications filed by residents as a means to assess technological innovation outputs. Hu also introduced national R&D expenditure and the number of residents using computer and internet access as other indicators to evaluate national capacity for R&D and to use new technologies and global information respectively. With these five criteria, Hu concludes that China is already a "strong innovator " and the country would overtake S&T great powers such as Japan and the U.S. sooner or later and become the world's largest S&T power.

Furthermore, there are researches that specifically focus on patents to evaluate the S&T advancement of a country. Along with R&D spending, Vincent

Shie and Craig Meer (2010) compared the S&T capacity of four Asian developing countries of China, India, South Korea, and Taiwan with those two highly developed countries of Japan and the USA. The authors used R&D expenditures, patent applications, and patents granted to demonstrate the gap between these countries. The article concluded that these two advanced economies retain formidable leads despite the rapid catching up and substantial achievements of these four latecomers in their IT undertakings (Shie and Meer, 2010). Renai Jiang, Haoyue Shi, and Gary H. Jefferson in the same vein compared China's S&T advancement with other highly industrialized countries such as the US, Japan, South Korea, the United Kingdom (UK), Germany, and France. The authors used data provided by the WIPO and the United States Patent and Trademark Office to analyze the number and quality of patent grants issued by each country (Jiang, Shi, and Jefferson, 2020). They argued that China shows outstanding S&T development, notably in patent performance at the global frontier as it produces more patents. However, when it comes to the quality of patents, they insisted that the quality adjustments show less impressive gains for China's case particularly concerning semiconductors.

Kennedy (2016) who compared China and India's S&T innovation progress also adopted traditional but the most widely used indicators of innovation: national expenditure on science-based R&D, scientific publication, and patent. He firstly developed a comprehensive framework that differentiates followers from

innovators. He emphasized the more a country advances technologically, the more science-oriented its R&D should become, and that it can also be expected to result in more patents and publications. In other words, active government support of science-based R&D and a strong S&T related international publication and intellectual property orientation are the foundation for enhancing innovation. By contrast, less-developed countries that neglect innovation and provide less support to R&D, especially in relation to scientific publications and patents, will experience brain drain. The author concludes that China has handled innovation challenges more successfully, resulting in better innovation outputs than India.

In the case of the hermit state which does not share any official statistical data – such as national budgets or R&D indicators– a lack of data has led previous literature to disregard and even avoid any quantitative analysis of North Korea's S&T innovation or economic capability in their discussions (Lee, 2014). Thus, few research has been taken to analyze North Korea's S&T capability other than focusing purely on its policy or specific fields of science to indirectly estimate its capacity. However, such limitations can be overcome by adopting science publication and patent data as tools to measure its related capacity. Along with many scholars who used these two as an indicator to conduct cross-national research, there are also very few scholars who used one of these methods to diagnose North Korea's S&T status. For example, Choi (2006) analyzed North Korea's academic literature by investigating the number of papers being published

by a research institute from 1985 to 2005. Kang (2007) on the other hand, scrutinized the technological trends of North Korea by analyzing patent fields by source, the number of applications by subject, and the trend of the patent application by subjects from 1984 to 2003

Chapter four specifically evaluates the S&T capability of the two North Korean regimes and further compares it with those of other LMI states. While referring to the aforementioned literature that use classical S&T innovation indicators (the scientific publications within international journals and patent registration and applications by residents) to gauge the national S&T capability, this thesis also applies these two indicators to simultaneously analyze the capacity and the progress of North Korea's S&T innovation. In particular, for a country that does not share its official data, these two factors that are relatively accessible through electronic databases may be the only possible way to properly estimate North Korea's innovation outputs. In the case of North Korea's academic journals, it can be analyzed by their number and fields by searching its publication into SCIs. NK tech provided by KISTI (Korea Institute of Science and Technology Information) and Web of Science are used to track the records of North Korea's S&T publication into international journals as either joint or independent researches since 1999. It first counts the number of S&T articles published into international journals by different regimes then categorize them by subjects. In addition, North Korea's bimonthly (later changed to monthly) *DPRK Official*

Journal of Invention (Balmeonggongbo) provides an insight into the patent sector or trends that North Korea is focusing on. This paper uses it as a reference to analyze North Korea's patents as well as data provided by the Korean Intellectual Property Office. The paper also uses WIPO as another data source to analyze the number of other LMI states' patent applications by residents.

A number of scholars have compared and analyzed China and India's innovation capabilities through the quantitative analysis of their international journals and patents. Likewise, a more objective evaluation of North Korea's S&T can be achieved if its output is compared with those of other LMI states with similar economic scales. This paper also compares the level of innovation outputs of North Korea and those of other LMI states such as Bhutan, Cambodia, Mongolia, the Kyrgyz Republic, and Lao PDR based on the aforementioned indicators. It finds that North Korea's current progress is quite impressive compared to previous regime and even that of other less industrialized countries. However, North Korea's high level of government intervention and control of closed markets, and nuclearization limit its potential to enhance innovation in the future.

III. Transition of S&T Policy Under Two Regimes

1. S&T Policy by Kim Jong-il

1-1. Policy background

Kim Jong-il sought to resolve internal problems by achieving the second and third industrial revolutions through S&T development. The demise of the Soviet Union and the end of the Cold War triggered destitution for North Korea. The collapse of the socialist economic system worldwide suddenly cut off North Korea's foreign currency exchange inflows, production equipment, and raw material imports, leading to a severe economic downturn. Then the sudden passing of Kim Il-sung in 1994 and Kim Jong-il's accession to power caused internal turmoil that Kim Jong-il tried to resolve by building a strong and prosperous nation through nuclear and IT development (Park, 2007). Kim Jong-il asserted that an S&T-based policy was the most strategic pathway to becoming a great power and that a nation's economy and military strength depended on its S&T. He firmly believed in the notion that "a socialist powerhouse is an S&T powerhouse." Kim Jong-il strived for economic recovery and growth by developing sophisticated S&T-implemented industries.

More importantly, North Korea's emphasis on S&T following observation of China's rapid economic growth between the 1980s and 2000s was begun by Kim Jong-il. Under Deng Xiaoping's integration of the socialist market economy and the open-door reforms of 1978, China's economic growth rate became the fastest in the world. The country's cheap labor and rent attracted vast foreign capital, and China eventually rose to become the world's largest exporter of goods (BBC, 2019).

The country has maintained an average annual GDP growth rate of 10 percent for the last two decades, and the living standards and personal income have improved remarkably (Li, 1998). In order to maintain its economic growth rate, China found its potential of economic boom not through agriculture, but high-tech industries (Han, 2019). During the 16th National Convention in 2003, a list of high-tech industries was established in order to provide tax benefits and funding for the IT industry and attract foreign investments. In order to foster IT, the government placed workers into the S&T innovation movement converged it with education, research, and production. Its open-door policy, along with a rapidly expanding IT industry, allowed China to acquire significant amounts of capital inflow and exports, which in turn allowed the country to leapfrog instantly from Industry 1.0 to Industry 3.0. The government especially designated Zhongguancun as the Beijing High-Technology Industry Development Experimental Zone in 1988 and become China's version of Silicon Valley. Zhongguancun hosts high-tech enterprises, research centers, and universities that have become the backbone of China's S&T innovation. Kim Jong-il's visit to this area in 2000 allowed him to study and benchmark China's case (Institute for Unification Education, 2019). Kim realized the importance of IT and the limitations of the heavy-chemistry industry that North Korea had been investing in; the beginning of North Korea's first trial on leapfrogging with S&T-oriented policy.

As a result, Kim Jong-il formulated the leapfrogging strategy to rapidly

achieve economic growth through the S&T especially the IT industry while also maintaining the socialist system. Kim Jong-il's leapfrogging strategy entailed immediately reaching industry 3.0 rather than following a phase-based motion from agriculturalization to industrialization and towards informatization. This strategy, if successful, would have made North Korea an economic powerhouse by minimizing the time needed for economic development (Seo, 2001; Byun, 2010). Kim Jong-il realized that the only means he had to break the status quo of simply chasing after advanced countries would be to reduce agriculturalization and industrialization and focus primarily on IT. Kim Jong-il's "even if factories may stop, but S&T development budgets will be secured first" resonates with his determination to prioritize and focus on the IT industry in order to overcome North Korea's economic struggle (Kim, 2002).

1-2. S&T in reality: a tool for economic recovery

North Korea faced unprecedented famine with an economic crisis a year after Kim Jong-il came into power; Arduous March. It was the hardest moment for North Korea resulting in estimated death of 330,000 in the year between 1996 and 2000.[4] The demise of the Soviet Union that led to less support for North Korea caused

[4] The exact number of deaths during the Arduous March is not clear. According to a 2010 analysis based on the UN's Population Census, the death toll is estimated to 330,000 in the year between 1996 and 2000. However, according to the U.S. National Statistical Office, the number of people who died from famine directly and indirectly in the year between 1995 to 2000 is estimated as 500,000 to 600,000.

food production and energy imports to decline at the same time a series of floods and droughts exacerbated the crisis. Kim Jong-il in response announced “strong and prosperous nation (kangsongtaeguk)” in 1998 in order to maintain regime stability from the internal and external crisis. However, North Korea officially ended its Arduous March during the two-day “National Self-reliance Demonstration Conference” in January 1998, and put forward the slogan "the strong and prosperous nation by self-reliance (Juche)” (Institute for Unification Education, 2012).[5] Such nation is believed to be accomplished by fulfilling ideological power, a political power, a military power, and an economic power. The point is, science is considered as one of the three major pillars in constructing the strong and prosperous nation (Bae, 2001).[6] The essence of S&T-oriented policy was the belief that any problems raised during the construction of a strong and powerful nation can be solved based on S&T; scientism. In particular, S&T is considered as the primary means of laying the foundation for socialist development and recovery from the economic downturn. With internal and external difficulties surrounded by North Korea, S&T development was thought to be the breakthrough

[5] Ever since North Korean media described the "Arduous March" with a past tense from 1998, it is reasonable to regard the year 1997 as the end of the North’s great famine (Institute for Unification Education, 2012).

[6] The first is the ideology powerhouse. Ideas take an important role in building a strong and prosperous nation since the country lays its socialist foundation by ideology. It is believed that socialism can collapse regardless of military and economic power if the idea collapses. The second is the “Gun-first” pathway, a line that puts top priority on national defense and the military under the belief that "peace and socialism maintained by gun power" Third, it is an S&T-oriented route (Institute for Unification Education, 2012).

to protect the country from international isolation and economic crisis, strengthen national defense, and further build a strong socialist state (Byun, 2016; Kim, 2000). Since the 2000s, the North's news media has been repeatedly reported the significance of S&T with the perception that "a new shift in the development of S&T will lead to solving numerous problems emerged from the construction of a strong and prosperous nation," (Institute for Unification Education, 2012).

Unlike Kim Il-sung's reign, in 2000, North Korea has come up with a five-year plan for S&T development equating it with an economic development strategy. In particular, IT was added into the second five-year (2003-2007) plan of S&T, which resulted in the national activation in fostering the IT industry. North Korea then declared leapfrogging via the IT industry.

"It can't be denied that there are steps for development. However, if we keep following by step by step, we never can surpass others. Our emphasis on S&T calls for a leap in the development of science and technology, regardless of the conventional stage of development nor established formulas. It is our will to bring accomplishments in all areas of S&T studies within a short period of time."

A Joint Journal of Geunroja and Rodong Sinmun (KCNA, 2000)

Since then, North Korea has regarded the "21st century as information industry age" and "advanced science and technology as computer industry." The country came up with various ways to foster IT including S&T exhibitions, IT-related

research debates, and continuous S&T promotion through media (Byun and Choi, 2012).

However, in reality, Kim Jong-il promoted S&T as a means of economic recovery rather than S&T as a key to accomplish a strong and prosperous nation. Kim Jong-il's was struggled to handle current technical problems such as extreme deficiency in raw materials, fuel, and food, financial difficulties, and inefficiency brought by the socialist planned economic system. In particular, the S&T during the Kim Jong-il's era was heavily used in food-related industries to solve food shortages. This was because North Korea's economy began to fall behind in the late 1980s when the Soviet Union began to show signs of disintegration and its support of economic reconstruction or investments and technologies were cut off. By the 1990s, the country faced an economic recession that it was difficult to implement a state-led planned economy. As a result, it was almost impossible for the government to introduce new industrial technologies and develop new materials or technologies. Alternatively, Kim decided to focus on overcoming the current crisis as its production facilities were severely destroyed in the wake of the great famine, and repairing them, hoping to repair and return production system to normal. The development of machinery, materials, and products in the chemical and metal sectors was intensively scrutinized to improve the deficiency caused by outdated technology and equipment.

Aforementioned, overcoming food shortages was the most urgent issue to

be resolved, thus, most of the facility supplementations were administered to light industries such as agriculture and food factories. In the process of repairing the light industry, the country also made efforts to modernize its production process by introducing IT technology (Lee, Ahn, and Chung, 2011). In the case of North Korea, soybean paste, soy sauce, and salt are considered as “basic food” and valued as one of the core food products. Modernization of basic food factory was planned to be implemented to one in three direct cities in 2000 except Jagangdo (Yonhap, 2001). In the same year, there has been a report by KCNA (2000) introducing the 112th chicken plant as a factory comprised of cutting-edge S&T systems, boasting computerized processes of chicken feeding, egg production, temperature control, and sewage purification. Pyongyang Seopo Chicken Factory, Mangyongdae Chicken Factory, and Ryongsong Chicken Factory had also been taken place as an exemplary modern factory carrying out computerization. In 2005, a couple of reports praised the improvement of S&T in the light industry by saying, "lots of livestock bases have been created…...we were able to increase the production of meat and milk eggs through modernization despite the hardship we suffered,” (KCNA, 2005). North Korea has also strived for developing agricultural technology by mobilizing computer centers of the Academy of Agricultural Sciences, universities, research institutes, and experts on land planning. Through S&T, they have sought to improve crop placement and seeding, efficient use of rice seeding, and chemical fertilizers. The same applies to the fisheries industry, where

a system to manage fishing grounds and fishing boats through data analysis by computers was established.

1-3. Seeking comparative advantage via IT industry

Although S&T-oriented policy was tilted to recovering economic downturn by supplementing light industry and thought by many scholars that no substantial contribution to North Korea's economy was ultimately made, the North Korea tried to adequately support and develop IT industry (Go, Lee, and Chang, 2007). In the midst of limited resources, international isolation, and economic recession, North Korea had to set up a selective industrial policy to make a single leap forward. Thus, it chose the information industry, especially the IT and computer software industries, as a comparative advantage.[7] It was not until 2002 that the importance of the information industry began to emerge. In 2003, the term '"the era of Information" was introduced by emphasizing, "we should earnestly learn advanced technology and actively absorb these cutting-edge S&T to meet the needs of such information era" (Byun, 2018). Ever since Kim Jong-il expressed direct interest in IT, North Korea has focused on the IT industry, specifically the software sector.

"If the 20th century was the age of the machinery industry, the 21st century would

[7] Although Kim Jong-il showed his interest in nanotechnology (NT) and biotechnology (BT), it was the IT industry that he heavily focused on S&T investment (Byun, 2010)

be the age of the information industry. In the age of mechanical industry, the creation of material wealth was largely based on physical labor. In the age of the information industry, it will be based on intelligence."

Statement by Kim Jong-il (Kim, 2005)

North Korea had no choice but to focus on the software sector as developing software over hardware was an easier and more realistic option for the hermit state. "Wassenaar Arrangement" did not allow North Korea to import semiconductor manufacturing technologies and facilities, thus, the country had its problem with poor technology and capital conditions (Kim, 2015). Accordingly, North Korea decided to focus on software that does not require heavy investment but allows a quality workforce (Kim and Hwang, 2004).

North Korea's software programs are developed by research institutes such as Kim Il-sung University, Kim Chaek University of Technology, DPRK Academy of Sciences, Program Information Center, Korean Computer Center, and Silver Star Computer Center. It is also studied under the principle of "Juche," making it clear that North Korea will ultimately develop its own program without relying on foreign software technology (Ko, Lee, and Chung, 2007). In this respect, North Korea's software program is ironically used for strengthening its regime ideology and stability by incorporating the idolization of Kim's family and *Juche* into the

programs.[8]

Table1. Computer software programs during the Kim Jong-il's regime

Computer Operation	Bulgeunbyeol (Red Star:2001~2008)
Document	Changdeok 7.5 (Chosun language editor), Seogwang (electronic publisher), Dangun 4.81(multilingual input system), Changdeok, Dangun (North Korean version of Word document comprised of 200 types of Korean handwriting), Seo, Noeul, Dambo, Pyeongyang, Yongma (table calculation program)
Translation	Mangyeongbong (Korean-Japanese translator), Damjing (Korean-Japanese translator), Korean translator
Recognition	Mongnan, Ryongnamsan (letter recognition), Chiljosan, Cheonji (letter and voice recognition), 127-3 (voice recognition), Sin-dong 2002 (letter recognition), Consecutive Voice Recognition for Korean Language
Entertainment	Eunbaduk(Go game), Ryugyeongbaduk (Go game), Chosun Janggi 3rd edition, Bureuna (Janggi program), Binma (Golden Horse; system of physical classification), Samilpo (a karaoke program with 4,150 songs), yeji (basketball tactical guidance system), Beongae 1.0 (comprehensive motion response inspection system)
Digital	Gwangmyeong 2003 (S&T encyclopedia), Saengmyeongui giwon (content related to human evolution), Mt. Baeduk: the Sacred Revolutionary Place, History of Chosun and people, Byeol (economic dictionary), Eunbangul (music editor)
Industrial Use	Ppuri, Choeryangkaem, Tamsaek, Manpungho (land readjustment design), Supung (hydraulic production plan), Sagye (fisheries information)

Source: Author adopted from KCNA articles, Institute for Unification Education (2006), Korea Finance Corporation (2010)

Table 1 shows North Korea's software program can be classified into six types. First of all, Red Star is a computer operation program. The most widely used program Windows was considered somewhat problematic for North Korea due to

[8] For example, North Korea's IT products reflect the idolization of Kim Il-sung and Kim Jong-il. They were programmed to let their leaders' name to appear in the keyboard shortcut; Ctrl+I for Kim Il-sung, Ctrl+J for Kim Jong-il, and Ctrl+K for Kim Jong-sook. Also, propaganda messages such as "we do when the party decides" and "production, learning, as required by Juche" are to appear on the monitor screen in various industrial programs (Nam, 2002).

security and license issues (Lee and Hwang, 2004). The country needed alternatives that could be used as a computer operating system. Accordingly, North Korea has stepped up its OS development based on Linux thanks to active research continued by the university, research institutes, and research centers. In particular, North Korea invented the Linux-based computer operating system called Red Star invented by the Korean (Chosun) Computer Center. The first version was released in 2006, followed by the second, third, and fourth versions in 2008, 2010, and 2011 respectively (Park, 2015). Although "Red Star" operates in a completely different system compare to Windows, its design is somehow similar to Windows XP with its start button being replaced by a big red star (Lee and Hwang, 2004). Furthermore, North Korea no longer rely on Windows as inventing independent literacy systems, as well as North Korean language programs, were inevitable. Accordingly, one of the most important areas of North Korea's software development turned out to be programming document, translation, and recognition software. Changdeok is one of the most commonly used documents editing programs in North Korea. It is equipped with basic editing functions, just like the South Korean Hangeul 97, and it also includes functions that automatically modify spelling and spacing, as well as functions that allow editing pictures, data, and shapes. About 200 types of handwriting are stored in the program (Ministry of Science and Technology, 2002). North Korea at that time was known for having outstanding recognition software. For example, “Consecutive Voice Recognition

for the Korean Language", developed by a Pyongsong College of Science, was sensational and it was introduced as "the program that computer itself can edit by listening to users voice," (Ministry of Science and Technology, 2002). In addition, there were other various software programs such as Beongae 1.0 (comprehensive motion response inspection system), Eunbangul (music editor), Eunbaduk (Go-game), which placed first in the 1999 World Computer Baduk Competition held in Japan, and Gwangmyeong 2003 (S&T encyclopedia).

After the announcement of its S&T-oriented policy, North Korea also tried to revitalize its network system; intranet.[9] In 2002, North Korea completed the construction of an intranet nationwide where Gwangmyeong was connected to 1,300 institutions and businesses, including central institutions, universities, and state-owned factories and enterprises (KCNA, 2014). Gwangmyeong, the only portal site during that time was open to the public which allowed individuals to access scientific and technological data, and media outlets such as KCNA and Rodong Sinmun. More interestingly, the government permitted opening an intranet cafe near Kwangbok Station in Pyongyang in the same year. The cafe has consisted of 100 PCs mainly open to Pyeongyang's upper middle class and university

[9] In North Korea, the information network is operated by two tracks: internet and intranet. Internet is used for foreigners accessing overseas websites and the internet is for North Koreans, a closed internal network. The government operates in dual structures as national security and information control is of utmost importance in stabilizing the regime. Accordingly, North Korea strictly ban digital access to the internet for domestic users.

students connecting all of North Korea's Intranet. Although the charge for using the computer is costly, the place was usually full of people (Seliger and Schmidt, 2014).

Furthermore, mobile communication was initiated in 2000 after the completion of North Korea's first telecom connection via satellite. Mobile phones were introduced to mainly Pyeongyang elites since 2002, and roughly 20,000 to 30,000 people are estimated to use mobile phones in 2004. The number has dramatically increased and popularized when it comes to Kim Jong-un's regime. However, North Korea still insists on separate mobile phone systems for foreign and domestic users that North Koreans can only communicate among themselves (Seliger and Schmidt, 2014).

2. S&T Policy by Kim Jong-un

2-1. Policy background

Kim Jong-il's strategy of leapfrogging via S&T has been passed down and further reinforced by Kim Jong-un, who also finds it as a key to overcome the national crisis and achieving economic growth. Kim Jong-un hopes to achieve leapfrogging through the political framing of the IRNC strategy. This act increased the legitimacy of Kim Jong-un's regime not only by inheriting Kim Jong-il's policies but also by distinguishing it from the previous regime through the political branding of the IRNC. Kim Jong-un pushed for the fourth five-year S&T

development plan between 2013 and 2017, persisting Kim Jong-il's five-year S&T development plan. While Kim Jong-il expanded the entire field of advanced S&T to increase production capacity through informatization, automation, and modernization in the latter half of his regime, Kim Jong-un built upon his predecessor's work and has focused on High Technology (HT) such as computerized numerical control (CNC) and AI along with basic sciences such as nanotechnology (NT), biological technology (BT), new materials and energy.

Externally, China's success in becoming a Group of Two (G2) through its leapfrogging policy and its Made in China 2025 initiative prompted North Korea to proceed with the IRNC with confidence. China's confidence in fostering S&T innovations led the country to use it as the means to seek another leapfrog in the 21st century. China, whose GDP ranked 10th in the world in 1978, overtook Japan's GDP in 2010, reaching the second largest GDP worldwide. By 2010, however, China was no longer be able to grow at 10% annually, instead, humming along 6–7% by 2015. Regional imbalances, income gaps between classes, environmental issues, the economic slowdown started by in the West since 2000, and the 2016 U.S.-China trade war hindered China's economic growth (Yang, 2013). President Xi Jinping thus asserted three characteristics of China's economy and announced a way to address this relative economic decline during his 2014 Asia-Pacific

Economic Cooperation (APEC) speech.[10] The solution he called for was to augment China's industries by revitalizing its industry 4.0. By benchmarking Germany's version of industry 4.0, the initiative Made in China 2025,[11] put forward as a key to China's continued leapfrogging, was formulated in 2015. In 2016, China announced its National Innovation-Driven Development Strategy,[12] which gave the detailed version of the Made in China 2025 initiative.

China surpassing other industrialized countries and competing against the U.S. under the government's control and planning indicates to North Korea that its IRNC may be the key to upgrading its economic status. Following Kim Jong-il, Kim Jong-un visited Zhongguancun on his first visit to China in 2018, observing hundreds of research institutes, universities, and enterprises that are complexed in

[10] The three characteristics of China's economy, in the words of Xi Jinping, are as follows. First, China's rapid growth rate has diminished. Second, the economic structure has changed. Third, the economic growth engine has changed from an investment-driven to an innovation-driven one (Kim, 2018).

[11] Made in China 2025 calls for China to become the world's greatest manufacturing and internet powerhouse by developing the world's foremost technological and industrial systems. This involves three planned ten-year phases of development until 2045. The first phase calls for China to become a leading manufacturing power by 2025. In the second phase, China is to maintain its position in the middle among other advanced manufacturing states by 2035. The third phase is to see a celebration of the 100th anniversary of New China and the achievement of the rank of the world's greatest manufacturing country by 2049 (Han, 2019). China expects much from industry 4.0, as this is the first time the country has taken part in an industrial revolution wave on the same terms as the most advanced countries.

[12] The National Innovation-Driven Development Strategy consists of a three-phased industrial policy. In the first phase, R&D expenditures are to be increased up to 2.5% that of GDP to reach the status of an innovative country by 2020. In the second phase, R&D spending is to grow to 2.8%. The third phase is, by 2050, to see a structure established where the ideas of follower, late innovator, and innovator coexist rather than simply allowing the country to chase and apply the S&T of advanced innovators (Yun, 2016).

the area, producing massive S&T innovation. Kim's visit to China stimulated him to push ahead with the IRNC. The government's budget for S&T increased from 7.3% to 8.7% in 2019 and increased again to 9.5% in 2020. Also, Kim Jong-un has devoted himself to fostering and supporting S&T producers more than his predecessors. He has personally visited research facilities to receive and resolve feedback and has guaranteed optimal research and living conditions for scientists and technicians.

While Kim Jong-il hoped to bring North Korea's economy to recovery and leapfrog from industry 2.0 to industry 3.0, Kim Jong-un seeks to augment industry 3.0 while simultaneously leapfrogging to industry 4.0. His belief that a nation's fate lies with its science and technology is the basis for his determination to construct a strong knowledge economy by pursuing S&T innovation and advancement despite international isolation and sanctions (Kim, 2015). To achieve this vision, Kim Jong-un has invested in innovation development more than any of his predecessors and even personally visited research teams, showing a dedication hardly seen under previous regimes.

2-2. S&T via the IRNC: objective for building socialist economic powerhouse and knowledge economy

Industrial Revolution of the New Century (IRNC) refers to the science and technology innovation strategy pursued by the Kim Jong-un regime to accomplish

a knowledge economy and socialist economic powerhouse. The IRNC can be broadly interpreted as "the cutting-edge breakthrough advancement to construct a knowledge economy, and the government's strategic vision of founding a powerful socialist nation" (Kim, 2013). The purpose of the IRNC is to accomplish S&T innovation to construct a knowledge economy powerhouse, based on the nation's augmented independence and self-reliance (Cho, 2013). Science and technology, which was considered as one of the three pillars to building a strong and prosperous nation during the Kim Jong-il era, is now accepted as a national leading goal. Kim Jong-un has stressed S&T in every new year announcement that the nation should pursue economic growth via science and technology.[13]

A number of news articles had repeatedly reported the meaning of knowledge economy since the inauguration of Kim Jong-un. Knowledge economy,

[13] Kim Jong-un mentioned the importance of science and technology in his annual New Year's address as follows: "we need to make a breakthrough in the construction of an economic powerhouse with the power of science and technology by vigorously stoking the flames of the IRNC (2013)." "Science and technology are the driving force in the construction of a strong socialist nation, and the happiness of the people and the future of our country depend on the development of science and technology (2014)." "We need to implement science and technology in every sector, every unit, and we need to actively modernize and informatize our way of life, raise the level of science and technology for workers, and vigorously expand every side of business based on science and technology (2015)." "Our party has a firm determination to solidify the foundation of a powerful nation via science and technology (2016)." "The power of self-reliance is the power of science and technology (2017)." "Scientists and engineers have fiercely worked on the development of the economy and the improvement of people's lives by completing high-tech research tasks and improving scientific and technological innovation under the construction of a socialist powerhouse (2018)." "Human resources and science and technology are our main strategic resources and weapons to leap forward in socialist construction. The nation should promote human resources and science and technology innovation in a goal-oriented manner and increase governmental investment in them (2019)."

like other industrial countries, simply means an economy based on knowledge. If Kim Jong-il pursued IT to revitalize the light industry and solve food shortage problems, his son aims to maximize production through S&T innovations brought by current knowledge and knowledge-based industry. In particular, Industry 4.0 recognized by industrialized countries is a manufacturing innovation that seeks to maximize the efficiency of production by combining IT systems with manufacturing (also known as smart factories), thus, when manufacturing innovation takes place, automation of unmanned factories will be accomplished. Likewise, North Korea is also doing its best to innovate science and technology in line with this global trend via the Industrial Revolution of the New Century (IRNC), aiming to achieve CNC, integrated production management system by computers, and unmanned production system.

Indeed, Kim Jong-un insists on the modernization of the overall industry by converging science and technology with other fields of the industry ever since his declaration of the IRNC. In his 2013 New year's message, for instance, he stressed that many factories and companies so far have been initiated modernization based on modern science and technology and that CNC and unmanned production processes should be actively realized further in the future. In the same vein in 2014, he called for all North Korean workers to learn science, thereby innovation should take place in overall people's economy even in a basic industrial sector such as the light industry. In 2015, Kim praised the working class,

scientists, and engineers that “they successfully pioneered a new pathway for overall economic development and improvement of people's lives by actively realizing the modernization and informationization of the production process in the era of the knowledge economy."

Above all, the importance of science and technology has further appreciated after the 7th Congress of the Workers' Party of Korea (WPK) since the party declared achieving an S&T powerhouse as a national primary goal in line with building a socialist powerhouse. Thus, the Workers party reinforced the significance of S&T on their decision paper by stating it as "the most important strategic resource of the country and a strong driving force for social development,” (Workers' Party of Korea, 2016). In addition to such a statement, it also emphasized that “this is the party’s will and determination to foster S&T powerhouse within a short period of time to bring about a revolutionary turnaround in socialist construction.” Thus, unlike some scholastic views, North Korea is sincerely responding to it as part of a national strategy rather than considering S&T in the form of propaganda. Also, several statements mentioned in the decision paper such as "leading economic development via science and technology," "pioneer and develop economic-science" and "science and technology, the driving force in building an economic powerhouse" tell that the country equates S&T innovation as economic growth. The party also showed its readiness as an innovative country by saying, “in order to accept the advanced S&T from other countries in a timely

manner to suit our situation, …… information technology, nanotechnology, biotechnology, and other key basic sciences should be the cornerstone of establishing a world-renowned quality of research," (Workers' Party of Korea, 2016). Thus, it can be seen that science and technology, which used to be a means of economic recovery, has now been promoted to a national goal for economic growth and the creation of innovation.

2-3. Seeking comparative advantage via High Technology

Aforementioned, the purpose of the IRNC is to construct a knowledge economy and socialist economic powerhouse by achieving S&T competitiveness through its technological innovations and upgrading itself from obsolete industry 3.0 to swiftly leapfrog into industry 4.0. At present, North Korea is actively cultivating CNC and ICT-based advanced technology especially AI (most recently even robots).

The CNC technology is a combination of computerized numerical control and information technology that can boost resource efficiency at the same time add more precision to the final product (Park et al., 2018). The CNC development was originally initiated by Kim Jong-il which has been a significant element to the arms industry as well as in producing cutting-edge machines and weaponry. For the hermit kingdom packed with military-first ideology, CNC is a must skill to produce ICBM, SLBM and space launch vehicles. Since CNC import was prohibited thanks to the Wassenaar arrangement, Kim Jong-il decided to

concentrate on improving CNC technology for military use especially for developing nuclear weapons. With the record of CNC machines reaching 10,000 in 2017, North Korea is believed to have conducted a series of nuclear tests in 2013 following 2006 and 2009 (Kim, 2017). Military-purpose of CNC was then applied to space science for satellite space launch vehicle "Unha 2" in 2009 thanks to a high-performance multi-axis CNC machine (Byun and Choi, 2012).

The main difference in the use of CNC between the past and current regime is if Kim Jong-il fostered CNC for military use, his son looks for implementing CNC into diverse civilian industries to boost production and economic benefits thereby achieving a knowledge economy. If the previous regime emphasized the overall IT industry for leapfrogging, the current regime specifically focuses on Computerized Numerical Control (CNC) aiming to merge with every sector of industrial production and achieve automation and unmanned manufacturing at the end. Kim Jong-un believes a successful adoption of CNC technology into civilian use of manufacturing would bolster the quality of the North Korean production system (Park et al., 2018).

North Korea's CNC is composed of four phases. The first phase is to upgrade the level of CNC, and the second stage is to establish automated flexible production zones and apply CNC into production technology. The third stage is to establish a system where all production sectors are integrated, and the last stage is to achieve unmanned production (Lee and Kim, 2015). Kim Jong-un has been

pushing for the first phase of CNC across the country at the same time realizing the second phase of CNC into civilian manufacturing. As it was the first time for the country to apply CNC at the civilian level, the government decided to select a pilot group to set up and operate CNC in case of any technical and economic problems caused by insufficient understandings by the workers, lack of productivity, infrastructure, and supplements as accessories for manufacturing (Byun and Choi, 2012). Meanwhile, the current regime elevates the public expectation on the CNC by continuously emphasizing, "all economic sectors including metal, machinery, chemical, and light industries have made cutting-edge breakthroughs, resulting in the modernization of production processes as well as fundamental qualitative leapfrog in technological equipment," (Han, 2012). The CNC acceleration was paying off to some extent by 2015. The plants operated by CNC is reported to have reached more than 1,300 as of 2014 (KCNA, 2014). Given the fact CNC has only been implemented at the private level for a short period of time, its expansion rate is incredible, and it can be inferred that the number is likely to increase even higher. Also, there has been a number of news media reporting factories equipped with automation and automation-related production processes such as Pyongyang Socks Factory (2014), Chonji Lubricants Factory (2014), Pyongyang Corn Factory (2015), Ryongaksan Soap Factory (2016), Unha Daesung Food Plant (2017), Samjiyeon Potato Plant (2018), Cheongjin Kimchi Plant (2019), and Pyeongyang Wheat Processing Plant (2020). Also, robots introduced by the SAS and the Kim Chaek

University of Technology have been incorporated into production processes and are utilized for unmanned factory operation.

Furthermore, North Korea is coercively pushing ahead AI stimulated by the declaration of so-called the fourth industrial revolution during the 2016 World Economic Forum followed by Alpha Go's game against Lee Sedol. While research on artificial intelligence has been mentioned in some cases such as the "KCC Go-game" or "Korea medical," during the era of Kim Jong-il. AI and CNC have received more attention as his son came into power. Indeed, the cases of artificial intelligence Alpha Go winning the Go competition against humans in 2016 and the declaration of "the fourth industrial revolution" at the World Economic Forum in Davos in the same year stimulated North Korea to push ahead in developing AI. North Korea's leading media report, the Rodong Sinmun, even mentioned these incidents directly in its article, stressing the need of fostering creative and innovative talents against AI.

"In March 2016, a go-game was played between man and AlphaGo. The man lost several times against AlphaGo...It has been suggested that there will come a day where artificial intelligence will replace most of the knowledge-based human labor. However, this is not the main message of this incident. The point is, the man won the game against AI once. This was possible because the man has made new moves that have not been seen in traditional Go games. In other words, artificial intelligence knelt before human creativity. Although it was only a one-time victory,

it is still worthwhile as it gives a lesson that we should cultivate creative and innovative talented intellectuals. Competitiveness cannot be maintained in the era of the fourth industrial revolution with memorize-based human resources."

Rodong Sinmun (2019)

Reports on AI development began to frequently appear in North Korea ever since the introduction of "the fourth industrial revolution" in 2016. In 2017, Kim Il-sung University launched the Yongnam-san 5.1 project, an AI language translation program that translates English documents into Korean. Yongnam-san 5.1 is characterized by an unrestricted number of recognizable words with a voice recognition accuracy rate of 98%. Meanwhile, the multi-language character recognition program "Shindong," developed by the Kimchaek University of Technology, includes video pre-processing technology such as error correction from document images, automatic transcription division technology for automatic extraction of letters and pictures, and the literacy rate of 99.7%. In addition, the Mathematics Institute of the State Academy of Sciences has developed a face and fingerprint identification system that can be used for financial management, immigration control, and electronic payment (Sogwang, 2017). In particular, in 2018, the North Korean team won in the Critical Assessment of protein Structure Prediction (CASP), which tells that the North may have the world-class level of protein structure prediction AI (Moon, 2019). A variety of AI technologies were

introduced in 2018, including voice and melody recognition (Arirang Meari, 2018) and more advanced face-recognition program. Since 2017, North Korea also held an annual contest related to biometric technology as the current regime positively views biometric technology as, “a revolutionary high-tech technology that can be widely used in the diverse sector to improve life convenience, “(DPRK Today, 2018). Accordingly, in 2019, Kim Il Sung University came up with “Dambo,” thought to be the nation’s highest-quality face recognition device. It is an AI product that can automatically identify a person's face, his or her identification, and do the access control (Arirang Meari, 2019). In the same year, Rodong Sinmun (2019) positively anticipated the introduction of the AI weather forecasts that uses big data gathered for cloud movements.

The current regime is also interested in developing robots using AI technology. In 2018, Pyongyang Electronics Printing Technology Exchange Office introduced an automated table tennis training robot (Lim, 2019). In 2019, North Korea proudly reported that it succeeded in inventing a 6-DOF-articulated robot, which is known as the exemplary product of advanced countries, by its own S&T. North Korean scientists have been working on this robot for a long time as it required a combination of diverse cutting-edge technologies such as machinery, electronics, compressor technology, and artificial intelligence in making process. The report emphasized the benefits of inventing such a 6-DOF-articulated robot that it will accelerate automated and unmanned production that would reduce the

physical burden for the workers (Arirang Meari, 2019). Other types of robots applied with AI were also introduced at the S&T exhibition held in Pyongyang in 2019 (Ryugyong, 2019).

Table 2. S&T policy by Kim Jong-il and Kim Jong-un

	Kim Jong-il (1998~2011)	**Kim Jong-un (2012~)**
S&T Policy	S&T-oriented policy	IRNC
Background (Motivation)	-Economic recession -China's leapfrog,	-Justification of regime succession -Economic growth -Made in China 2025
Purpose	Leapfrog from the obsolete industry 2.0 to industry 3.0	Leapfrog from the obsolete industry 3.0 to industry 4.0
Objective	"Strong and prosperous nation" (*Kangsongtaeguk*)	Knowledge economy Socialist economic powerhouse
Leadership	-S&T as a means for economic recovery -S&T was not a priority in government support	-Cutting-edge breakthroughs -Acceleration of CNC into civilian manufacturing and production -Maximum support on S&T (realization of scientism)
Comparative advantage	-IT especially overall computer software	-HT especially CNC and AI
Accomplishments	-S&T for economic recovery -building foundation for ICTs	-Yielding innovations and succeed in catching up some of other LMI states

LMI*: lower-middle income state

2-4. Acceleration of innovation building: financial support and maximizing welfares in S&T

Under the Kim Jong-un regime, science and technological innovation is considered as the government's primary goal in order to achieve a knowledge economy and socialist economic powerhouse. Kim Jong-un believes that the quality of life and the prosperity of the country depend on the level of science and technology development. In this respect, he promotes better welfares for scientists and

engineers at the same time prioritizes the S&T budget to other economic budget allocations in order to yield more innovation rights after he came into power. This is one of the remarkable changes in the current regime.

Aforementioned in chapter two, the central concept of the IRNC is not new. Kim Jong-un inherited an S&T-oriented policy from his father to legitimize his policy. However, the Kim Jong-un administration's budget sharing seems to be more tilted to S&T. Although the exact outlay for the sector is not known, it can be inferred from Table 2 that the government has been continuously in support of S&T ever since Kim Jong-un came into power. Since 2014, the budget for S&T continued to rise, North Korea was seeing an average 7.5% increase in 2016 followed by an 8.7 % increase in 2019, and 9.5% increase in 2020.

Table 3. Annual increase in North Korean government's budget spending by sector

Year		2003	2004	2005	2006	2007	2008	2009	2010	2011
Overall Economic Budget	S&T	15.7	60	14.7	3.1	60.3	6.1	8.0	8.5	10.1
	Light Industry	12.4	-	-	-	16.8	-	5.6	10.1	12.9
	Agriculture	21.3	-	29.1	12.2	8.5	5.5	6.9	9.4	9.0
	Four Leading Sector*	42.8	-	-	9.6	11.9	49.8	8.7	7.3	13.5
	Construction	18.5	-	-	-	-	-	-	-	15.1
Year		2012	2013	2014	2015	2016	2017	2018	2019	2020
Overall Economic Budget	S&T	8.0	8.5	10.1	5.0	5.2	8.5	7.4	8.7	9.5
	Light Industry	9.4	5.1	5.2	5.1	4.3	4.5	5.5	5.7	7.2
	Agriculture	9.4	5.1	5.1	4.2	4.3	4.4	5.5	5.7	7.2
	Four Leading Sector	12.1	7.2	5.2	5.1	-	4.5	5.5	5.7	7.2
	Construction	12.2	5.8	4.3	8.7	13.7	2.6	4.9	5.9	

Four Leading Sector*: metal, electricity, coal industry and railway transport

Source: Author adopted form KCNA news report and Rodong Sinmun.

Kim Jong-il's regime seems to give better inputs into S&T investment if only observe the numerical value of the increase of the S&T budget expenditure not considering the proportion of S&T to the expenditures of other economic sectors. Although the S&T budget increase in the year between 2003 and 2005[14] was so high, the Table 3 indicates that Kim Jong-il in reality prioritized either constructions or light industry or agriculture and fisheries. Except in the year between 2007 and 2008, where the S&T budget dramatically increased to approximately 60% but also dramatically decreased to 6.1% in 2008, the rate usually stayed under 10%. The budget rate seems to stabilized since 2008 but still, the budget was less allocated to S&T compare to other industries. On the other hand, the numerical value of the S&T budget seems less significant during the Kim Jong-un's regime if compare to the previous regime. There was even a decrease in S&T spending in the year between 2012 to 2014, However, it was not that the government allocated less on the S&T compare to other industries; it was because of overall decrease in the budget for economic sectors. For instance, in 2013, the S&T budget dropped from 10.9 to 6.7 but other industries such as light industries and construction also dropped from 9.4% to 5.1% and 12.2% to 5.7% respectively. More importantly, unlike his father, Kim Jong-un prioritized S&T by allocating the

[14] 2004 and 2007 was the remarkable year for S&T expenditure since the government decided to spend approximately 1.6 times more than the previous year. However, the number seems unreliable since the budget spent on other sectors is not mentioned in the North Korean news report and the dramatic increase seems so sudden.

highest proportion of national budget into the sector compare to other industries listed in Table 3. Since Kim Jong-un's regime, the proportion of the light industry, agriculture and fisheries, and construction gradually decreased.[15]

In the previous administration, the government support of S&T was heavily fluctuated. The proportion of the S&T budget was usually less than other economic sectors except 2004 and 2007. Kim Jong-il declared the strong and prosperous nation in 1999 and reinforced science and technology along with ideology and military power as the three pillars of a 'strong and prosperous' nation. However, science and technology were treated as secondary budget spending compare to other economic sectors such as light industry or agricultures and fisheries or construction except in 2004 and 2007.

The North Korean government also has encouraged domestic businesses to increase their investment in S&T. The article "Establishing Knowledge economy in the Democratic People's Republic of Korea," published at Kim Il-sung University in April 2019 emphasized that "S&T expenditure has steadily increased in both governmental and business level, and the government is responsible for securing these business and funds necessary for S&T development" (Kang, 2019). Furthermore, the government has guaranteed optimal research and living

[15] 2015 and 2016 may be the exception as the construction rate increased but it was not that Kim suddenly neglected the significance of S&T, it was more to the fact that North Korea needed more infrastructure building during this period.

conditions for scientists and technicians to allow them to focus on their R&D, while expanding the target audience by holding scientific and technological debates, exhibitions, and presentations.

Meanwhile, brain drain is a chronic dilemma for developing countries as well-educated people leave their home country in pursuit of economic improvement and better education resulting in the lack of domestic intellectuals. Even though North Korea is free from this brain drain dilemma as the freedom of movement is not allowed in the country, Kim Jong-un is giving scientists unprecedented welfare benefits.

Various welfare benefits limited to scientists are implemented to elevate their motivation for further innovation outputs. The exemplary case is the government-planned living zones for scientists and engineers. On September 8, 2013, the Unha Scientist Street was completed under the leadership of Kim Jong-un. North Korean media such as KCNA and Rodong Sinmun, reported that Kim Jong-un frequently visited the place to carefully examine the construction process. According to Rodong Sinmun, “the scientists enjoyed the benefits of a strong nation first by receiving a palace-like but strangely looking house free of charge under the party's grace.” The media repeatedly published new articles that say “our dear head emphasized there is nothing to waste for scientists and engineers who contribute heavily to strengthening national power and improving quality of life,” and stressed Unha Scientist Street as the leading output of the party's science-

oriented policy (KCNA, 2013). The living complex is comprised of 21 buildings containing 1,000 households, local amenities such as schools, hospitals, kindergartens, and restaurants, and parks. Another construction project was initiated in March 2013 and completed in July 2014. These newly bult apartments were given to scientists all free of charge including blankets and furniture with the remark of calling scientists as "patriots" who devote their lives to the construction of his fatherland. In 2015, Mirae Scientists Street was also completed, creating another scientific residential area comprised of thousands of houses and 150 amenities mixed with more than 50 stories of skyscrapers (DPRK Today, 2015).

Kim Jong-un further provided various welfare benefits for scientists. One other example is the grocery store exclusive to Ph.D. and professors in science (not open to the general public) which was opened in front of the Victorious Fatherland Liberation War Museum. Similar to South Korea's welfare card system, the user can purchase goods equivalent to 700 euros by only paying a annual membership of 3,000 won (Lee and Kim, 2015). In 2014, the Yeonpung Scientist Resort was constructed, guided by Kim Jong-un, where scientists can enjoy various facilities – electronic libraries, various sports centers, and amenities – surrounded by forests and the lake.

IV. Innovation Outputs via the IRNC

The scholars of late development emphasized that followers require greater government intervention in order to cut down the time required to move on to the next development stage by concentrating growth in certain selected industries in search of a quick economic boom (Amsden, 1989; Johnson, 1982; Wade, 1990; Wang, 2018). Kennedy (2015) further added that producing more science-oriented R&D and resulting in more patents and publications are the foundation for enhancing innovation, the precondition for followers to becoming late-innovators. Otherwise, less-developed countries that neglect innovation and provide less support to R&D, especially in relation to scientific publications and patents, will experience brain drain. Their arguments have been partially reflected in North Korea's policy where the country actively pursues the IRNC but selectively pushes ahead S&T development under hierarchal socialist instructions. North Korea's strict top-down structure is a strategy that maximizes policy efficiency where each agency is assigned a mission to swiftly produce results toward a consistent goal. As such, North Korea's current socialist-based, top-down strategy in line with innovation outputs produced during Kim Jong-un's regime has resulted in greater efficiency. This chapter compares the innovation outputs drawn by Kim Jong-un's regime to those of Kim Jong-il's and other LMI states such as Cambodia, Myanmar, the Kyrgyz Republic, Bangladesh, Lao PDR, and Vietnam.

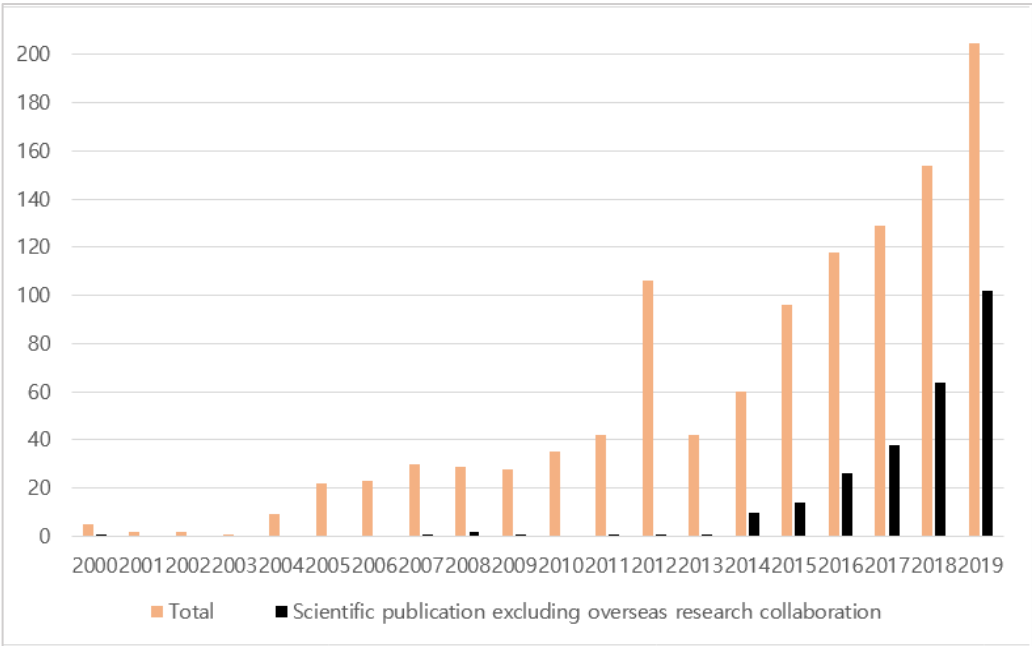
1. Registration of international academic journals related to science and technology innovations

1-1. Quantitative competitiveness of S&T journal publications

Despite Kim Jong-il's S&T-oriented policy since the late 1990s, there had not been a noteworthy output in S&T publication to the international journals until his son came into power. Figure 1 shows that the number of both S&T joint research and independent research by North Koreans remained roughly 22 to 42 and 0 to 1 respectively in the era of Kim Jong-il. The total number of S&T articles jumped to more than a hundred since Kim Jong-un's regime reaching 106 in 2012. In 2013, the number plummeted to 42,[16] but soon recovered and reached 205 in 2019. The total number of publications after Kim Jong-il's declaration of S&T-oriented policy was 229 by which had already been chased by his son in the first four-year of his rule. Under Kim Jong-un's regime, the number of international publications quadrupled to 910 in 2019.

[16] It is not likely that the sudden drop of joint research in 2013 was due to less government support in S&T. Since the same number of North Korea's independent research increased in the year between 2012and 2013. If governmental support in the research area weakened, both of these joint and independent research should have shown a decrease. Thus, it can be inferred that the aftermath of the UN's reinforcement in sanction against the North in 2012 may have negatively affected overseas research collaboration.

Figure 1. The number of independent S&T research registered in the international academic journal in proportion to the total number of North Korea's international S&T publications



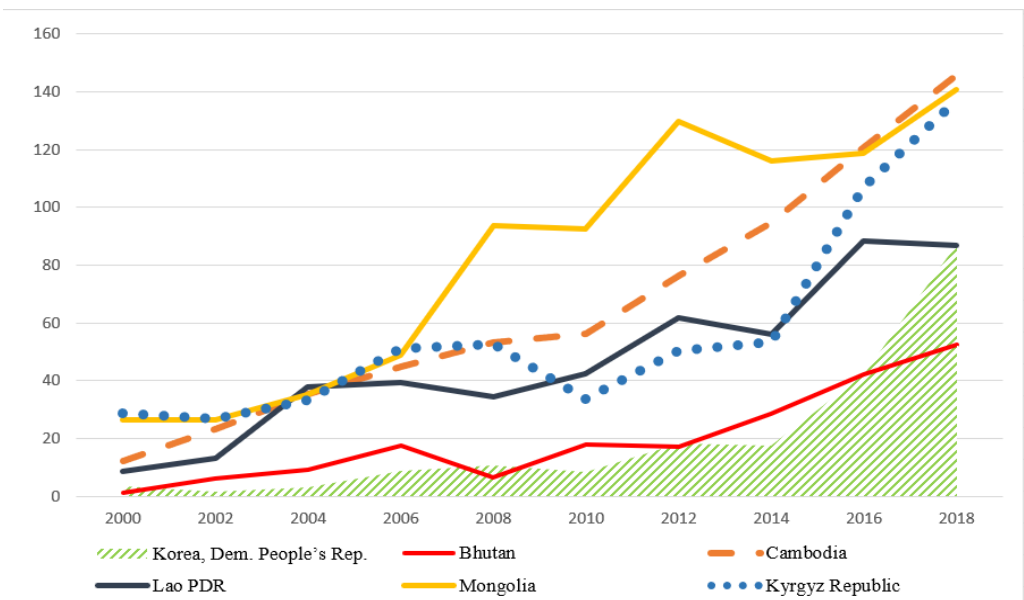
Source: NK tech and Web of Science

North Korea's S&T journal output seems more remarkable when it comes to its own independent research progress. During Kim Jong-il's regime, the research solely taken by North Korean scientists and engineers were hardly spotted. Only five articles were published into international journals during the previous government. It was not until 2014 more than 10 articles were annually being introduced into international academia. Soon the annual number of independent researches listed into international journals reached to 103 in 2019. Indeed, North Korea's dramatic increase in independent research is an important indicator to estimate the country's research capacity, and such improvement tells that Kim's

IRNC is practically in progress with innovation actually being made this time.

Furthermore, North Korea's IRNC achievements surpassed some of other LMI countries with similar economic scale, attesting to the potential of the country's S&T innovation. Aforementioned in chapter three, North Korea has annually increased its S&T budget by 7.5 % a feat unseen in peer countries. The country's incremental investment and prioritization of S&T are contrasting to other LMI states such as Mongolia and the Kyrgyz Republic where it has reduced its R&D spending. In terms of S&T-related international academic journals, while Bhutan, Cambodia. Lao PDR, Mongolia, and the Kyrgyz Republic have consistently registered articles in international journals, North Korea has done so at a rapid pace ever since Kim Jong-un came into power.

Figure2. The number of scientific and engineering journal articles published



Source: World Bank

Figure 2 shows the overall increase in S&T journal articles by countries.[17] When North Korea had remained less than 20 publications until 2012, these four other countries (except Bhutan) have already passed above 20 during the same period. However, the number of S&T journals dramatically increased since 2014, catching up with the innovation outputs of other LMI countries such as Bhutan in 2016, followed by Lao PDR in 2018. North Korea published 87 articles in 2018, successfully exceed that of Bhutan's 52 and Lao's 86 journal articles. Also, the gap between North Korea and other LMI states has narrowed down which implies North Korea's potential of catching up with other LMI states. At the beginning of Kim Jong-un's regime, the gap between this hermit state and other LMI states was huge as Cambodia, Mongolia, and the Kyrgyz had four, seven, and 2.5 times more publications than the North. While North Korea's number of publications began to dramatically increase since 2012, the other countries kept the same or even lost their pace in yielding publications. As a result, such a gap has been narrowed down to 1.6, 1.6, and 1.5 respectively. Should North Korea continue to pursue S&T innovation at a similar pace, it is possible for the country to surpass more LMI states soon.

[17] The number of S&T articles stated in Figure 1 and Figure 2 is different. This is because S&T publication data sourced by the World Bank articles exclude some scientific field such as computer science, material science, environmental science, energy, and biochemistry other than physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences. The cross-country comparison follows this World Bank's instruction to maintain data coherence.

1-2. Journals by categories

Ever since Kim Jong-il announced a strong and prosperous nation and science-oriented policy then passed down his vision to his son as IRNC, North Korea has consistently provided support on basic sciences such as physics, astronomy, mathematics, and chemistry along with engineering. Amsden and Tschang(2013) differentiated followers and innovation leaders by distinguishing between five types of R&D. Pure science (basic science), basic research, and applied research are three types of research commonly pursued by advanced countries (innovation leaders). Pure science focuses on finding new scientific principles, application research pursues knowledge to create new products, while applied research tries to differentiate new products “on paper” (Amsden and Tschan, 2013). Likewise, North Korea's intensive support for basic science and engineering with relatively high outputs of these studies, can be seen as having the basis for the North's potential to one step ahead to become a late innovator. In particular, the upsurge of the number of these three areas of research during Kim Jong-un’s rule has led to growing expectations for fostering innovation.

Table 4. The distribution of S&T articles published in international journals by subject

Kim Jong-il (1999-2011)					
	Subject	No. Publications		Subject	No. Publications
1	Physics, astronomy	39	6	chemistry	18
2	Engineering	32	7	Agriculture and Biology, Computer Science	23
3	Mathematics	29	8	Earth science and planetary science, medicine	10
4	Biochemistry, genetics and molecular biology	23	9	energy	8
5	Material science	22	10	Environmental science	4

Kim Jong-un (2012~)					
	Subject	No. Publications		Subject	No. Publications
1	Physics, astronomy	155	6	chemistry	61
2	Engineering	131	7	Agriculture and Biology, Computer Science	53
3	Mathematics	120	8	Earth science and planetary science, medicine	45
4	Biochemistry, genetics and molecular biology	118	9	energy	36
5	Material science	64	10	Environmental science	27

Source: NK tech and Web of Science

Table 4 above shows the distributions of S&T publications by subjects by different regimes. In general, basic science and engineering are mostly registered in both of the governments. The most frequently published fields during the Kim Jong-il era were physics, astronomy, engineering, and mathematics. However, publications of these sectors did not seem to have received scholarly attention. For example, none of its research has been cited except “Research on the drawing-up of the pole figure for orientation analysis of directional Si steel sheet” which was published in *Journal of Materials Science & Technology* in 2000 and “Control of IPMSM drive system for drum washing machine” printed into *7th International Conference on Power Electronics* in 2007. Even these articles were rarely cited as

the former was cited once and the latter twice. Instead, it seems like North Korea in the 2000s seems to have a relatively competitive edge in nutrition. The nutrition article, “Effect of irons declaration of North Korea's industrial food on irons status of infrastructure in the DPRK” submitted to *Pacific Journal of Clinical Nutrition* in 2008 was cited 11 times. However, such a record also had a limitation as the journal they submitted was not internationally inflectional enough since the journal belonged to the 50-75% group with an impact factor of 0.817. Given that there is no record of S&T articles being published into the top-tier journals, and only one article submitted to a journal with the impact factor above 1.0, it demonstrates North Korea’s ambitious but limited S&T capability during Kim Jong-il’s regime.

Furthermore, research output in computer science was not impressive enough despite Kim Jong-il’s strong ambition on the IT industry especially in computer software as a comparative advantage. It was not until 2007 the first article related to computer science was published into international journals, and only 13 articles were published from 2007 to the end of Kim Jong-il’s regime. Considering the fact that the overall number of S&T publications during Kim Jong-il’s rule was not as much as that of Kim Jong-un’s, this number is still low compare to the other publications in physics, astronomy, and engineering which has more than the total of 30 publications. The country which had never been able to publish a single IT-related article into international journals up until 2006 despite its ambition to support the IT industry, began to publish one or two articles since 2007. Although

such change seems a good start to strengthen national strength in this new sector, it can be inferred that the research on computer science in the Kim Jong-il period, in reality, was weak considering that not only all 13 publications were submitted to journals with low impact factor and citations, but also the country has failed to issue its independent research of computer science into international journals. Such circumstances may have affected Kim Jong-il's incomplete ambition on leapfrogging via the IT industry.

In contrast, innovation achievement can be clearly seen under Kim Jong-un's reign thanks to the dramatic increase of the researches in basic science and engineering. Various studies on engineering are taking place as many researches in this field has been published. Indeed, the future of the S&T race between advanced countries depends on High Technology (HT) skills. HT refers to technologies such as artificial intelligence (AI), computer software, electrical engineering, nanotechnology, nuclear physics, robotics, and biotechnology. Table 4 indicates that basic science, engineering, and technology, which are necessary elements in nurturing HT, are highly published under Kim Jong-un's rule. The most published field during the Kim Jong-un's period is engineering, with a total of 155 publications, followed by 131 publications in physics and astronomy, and 120 publications in materials science surpassing mathematics. In particular, the number of researches in computer science tripled to 61, encouraging the current government's goal of establishing a knowledge economy via CNC.

1-3. Contribution of North Korea's journals to S&T academia

Under Kim Jong-un's regime, more publications into international journals have seen in various fields of basic science and engineering. Of course, quality is as much as important as quantity when it comes to estimating the S&T innovation capacity of one nation. Even so, it is clear that the S&T innovation by current regime is far better than the previous regime. Only six independent research by North Korean scientists and engineers were listed in international journals during Kim Jong-il's rule, and even this small number of researches were not highly recognized. For example, the article, "Research on the drawing-up of the pole figure for orientation analysis of directional Si steel sheet" that was submitted to the *Journal of Material Science and Technology* in 2000 has an impact factor of 0.241 which journal itself was positioned 40 out of 60 of the same kind. It was not until 2007 that the article "Control of IPMSM drive system for drum washing machine" was published in *the IEEE 7th International Conference on Power Electronics* that had the impact factor of 1.289. However, this was an exceptional case as the country failed to list its name on one of the top-tiered journals above the impact factor of 1.0. This clearly demonstrates North Korea's lacking in innovations over the past regime.

Table 5. The list of North Korea's top-tiered articles referenced globally

	Journal	Rating	Citation	Impact factor*	Article
2014	Fractional Calculus and Applied Analysis	Q1	14	2.245	Operational method for solving multi-term fractional differential equations with the generalized fractional derivatives
2015	Electrochimica Acta	Q1	22	4.803	Asymmetric electrostatic properties of an electric double layer: a generalized Poisson-Boltzmann approach taking into account non-uniform size effects and water polarization
2015	Laser Physics Letters	Q1	6	2.391	Plasmonic amplification and suppression in nano waveguide coupled to gain-assisted high-quality plasmon resonances
2016	Journal of Power Sources	Q1	23	6.395	First-principles study of ternary graphite compounds cointercalated with alkali atoms (Li, Na, and K) and alkylamines towards alkali ion battery applications
2017	Signal Processing	Q1	159	2.209	A new color image encryption using combination of the 1D chaotic map
2017	Journal of Power Sources	Q1	32	6.945	Revealing the stability and efficiency enhancement in mixed halide perovskites MAPb(I1-XClX)(3) with ab initio calculations
2018	Journal of Materials Chemistry A	Q1	15	6.997	A first-principles study on the chemical stability of inorganic perovskite solid solutions Cs1-xRbxPbI3 at finite temperature and pressure
2018	ACS Photonics	Q1	12	7.143	Anapole Resonances Facilitated by High-Index Contrast between Substrate and Dielectric Nanodisk Enhance Vacuum Ultraviolet Generation
2019	Solar Energy Materials and Solar Cells	Q1	12	6.984	Effects of thiourea on the perovskite crystallization for fully printable solar cells
2019	Inorganic Chemistry	Q1	47	4.825	Two-Dimensional Hybrid Composites of SnS2 with Graphene and Graphene Oxide for Improving Sodium Storage: A First-Principles Study

* Impactor factor when the article was submitted

Source: NK tech and Web of Science

On the other hand, the journals registered by the scientists during the Kim Jong-un's period show a completely different outcomes compare to that of Kim Jong-il. Table 5 shows much scientific research solely by North Korean experts has been published into international journals with impact factors that exceed 1.0 and even above 6.0. For example, Jong, Yu, Ri, Kim, and Ri (2016) demonstrated their findings in *Physical Review B*, known as one of the top-tiered journals in Physics with an impact factor of 3.836, in 2016 regarding the calculation of the phase decomposition energy and investigation of electronic charge density change to measure the material stability. Their articles were cited 58 times. In the following

year, “A new color image encryption using a combination of the 1D chaotic map” was published in *Signal Processing* which has an impact factor of 3.47. The article introduces a way to make an effective chaotic system by utilizing two one-dimension (1D) chaotic maps (Pak and Huang, 2017). This work has been cited 159 times internationally. The very recent work done by Ri, Yu, Kim, and Choe (2019) proposed the 2D hybrid composites of SnS2 and graphene or graphene oxide (GO) layers on the basis of the first-principles calculations of atomic structures, sodium intercalation energetics, and electronic properties. The article was published in *Inorganic Chemistry* with an impact factor of 4.825, cited 47 times.

The table 5 illustrates the topic of the academic papers published in the international journal under the current government. North Korea is selectively focusing on advanced technology, basic science fields such as physics, mathematics, and chemistry, and ICT. The fact that the records of only six academic journals during the Kim Jong-il reign jumped to a few hundred by the current government shown in the Figure 1 also suggests that North Korea has improved their support for researchers to better conduct independent research without heavily relying on overseas work. Indeed, in 2018, 20% of North Korea’s SCI-level articles related to S&T were considered to be world-class, and 4% were globally recognized (Lim, 2019). Meanwhile, North Korea’s researches under the current government have externally drawn attention as their works are frequently cited by

other researchers. Indeed, some even expect that North Korea's big data processing technologies, quantum cryptography communications, and automatic translation technologies may be on par with those of advanced countries (Lim, 2019). In keeping with such improvement, researchers who frequently registered their works into SCIs or world-renowned academic journals have been frequently praised in the main news media. For example, Rodong Sinmun, KCNA, and Naenara came up with head titles such as "ace scientists" or "world-famous scholars" expressing their respect and favor to the scientists. The articles introduce their records of scholarships and refer them as patriots who are believed to enhance national prestige in S&T globally.

North Korea's overseas joint research, seems not much affected by incremental international isolation against the country as the number of overseas research collaboration increase annually allowing the country to yield high-quality of research. Table 6 shows the change of North Korea's number of joint research by country. Although Kim Jong-il declared a science-oriented policy in 1999, the research output was not sufficient enough, proving his S&T-oriented policy was more of a bridge to economic recovery. It was not until 2005 the country earnestly began joint research, after Kim Jong-il's announcement of basic plans for second and third S&T development in 2003. Accordingly, the number of joint researches less than 10 were doubled to 20 by 2005 and the number gradually increased since.

Table 6. North Korea's number of overseas joint research by country

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
China	4	2	1		8	14	10	19	17	19
Germany				1		2	1	7	5	5
U.S. A						1			1	1
South Korea			1				7	2		
UK						2	1	1	1	2
Italy										
Europe						2	1	1	1	4
Australia/ New Zealand						1				
Southeast Asia					1					
East Asia										
Africa						1				
Others										

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
China	17	30	77	36	38	64	82	80	78	92
Germany	13	2	15	5	5	5	9	6	7	7
U.S. A		1		1	1	1	4	1	4	4
South Korea			2						2	1
UK						1	2		2	1
Italy					1	1	4	3	5	1
Europe	1	1	6	1	6	1	5	3	3	7
Australia/ New Zealand	1	1	1			1	2	1	3	1
Southeast Asia	2	1	1	1		1				3
East Asia	1				1	1			3	5
Africa								1		3
Others			2			1		1	2	1

Source: NK tech and Web of Science

In reality, the pace and volume of these joint researches have been accelerated by the current government. The current status of overseas joint research shows two characteristics. First, more research collaborations with various countries are conducted despite strengthened sanctions and international isolation against North Korea. Research collaboration with Southeast Asian countries, European countries, and Australia hardly seen in the previous regime have slightly

increased. Even joint research with the U.S., which North Koreans consider as their main enemy, can be seen. Second, while the main partners for the joint research during the Kim Jong-il period were China and Germany, joint researches with China have dramatically increased to nearly 90% of the total research in the Kim Jong-un regime. The number of researches between North Korea and China has jumped from 14-20 research to 70-90 by the current regime. This was possible as the current government has encouraged many scientists to participate in projects sponsored by the Chinese government (Noh, Kim, and Choi, 2016). A number of research collaborations have been made between the countries' SAS and universities. The government believes that research collaboration with China has improved North Korea's knowledge production.

In contrast to the previous regime, which had a small range of research partners such as China and Germany as the main partner and occasionally with South Korea, the UK, and other European countries, the current government have expanded its partnerships further into Southeast Asian and African states. North Korea especially has collaborated with China for a long time mainly focusing on basic science or engineering, but the current government even expand research to materials science and computer science. In the case of Germany, joint research regarding plants, such as plant species or breeding, was originally conducted but soon their research collaboration further covered topics such as mathematics, physics, cosmology, and chemistry, and engineering. Also, North Korea has

conducted research regarding computer science and chemistry with France and quantum chemistry with Italy. Research collaboration with other European states covers a variety of subjects from genetics, medical research, virology to non-mainstream science such as planetary health, geology, fisheries science, and animal science. Interestingly, North Korea even conducted research collaborations with the U.S. However, such collaboration was more of the country participating in joint research between China and the United States rather than bilateral research cooperation between the U.S. and North Korea. There is a total of three studies conducted between North Korea and the U.S., two of which are mathematics and one for acupuncture. Nine joint research in the year between 2006 and 2007 and three research in the year between 2018 and 2019 were conducted between two Koreas regarding genetics and cybernetics. In 2019, inter-Korean research dealt with visual science.

2. Patent Registrations

Intellectual property rights are a hallmark of modern, liberal democracy. Socialist countries that do not recognize private property also recognize intellectual property rights, but they differ from those of liberal democracies (Korean Intellectual Property Office, 2019). North Korea suffered an extreme economic downturn in the 1990s when the Soviet Union collapsed, and its constituent states disbanded. To overcome such crisis, North Korea chose to pursue an open foreign economic policy,

which led to modify its conventional intellectual property rights, particularly, the protection of R&D investment performance and the investment expansion (Korean Intellectual Property Office, 2019). In this respect, North Korea's patent rights are a blend between the inventor's rights and patent rights. The invention rights belong to the inventor, but his authority to use the invention belongs to the state. Therefore, inventors are not allowed to revoke, give up, or transfer their right to the invention at the discretion of the inventor. However, advantages for having invention rights are that there is no burden for the registration fee for the invention rights, and political, moral, and material incentives are granted to the inventor (Korean Intellectual Property Office, 2019). On the other hand, in the case of patent rights, the right to use its ownership is monopolized to the inventor which means giving up or transferring its right is possible as with other capitalist states. The government allowed locals to acquire patent rights since 1986, but in reality, patent rights are usually registered by foreigners, and locals usually apply for invention rights. In 1998, the Invention Law was newly enacted for the development of science and technology and the reinforcement of the invention business.

Information on North Korean patents is only disclosed in *DPRK Official Journal of Invention*, a bimonthly journal published by the General Bureau of Inventions. Analyzing North Korea's patent outputs through this journal shows the transition of the government's efforts in fostering patents by observing the number of patents introduced in the journal and the quality improvement of the journal itself.

For example, the journal issued up until 2000 simply summarized the invention into two or three sentences, whereas the journal since 2004 includes invention claim and invention description to give more details of the item. Also, the journal further opened its patent information by adding a patent application section at the very beginning of the journal, listing title of the patent, date of the application date, and name of the applicant and organization.[18] The issue of *DPRK Official Journal of Invention* has also been differed by the level of the government's emphasis on S&T. The journal, which should have published bimonthly, had been reduced to a total of four publication annually since 1994 but soon recovered its position as bimonthly since Kim Jong-il declared the S&T-oriented policy in 1999, then the journal seems to become a monthly-based issue since 2009. Also, on the next page of the cover page of each issue, there is a phrase written by either Kim Jong-il and Kim Jong-un emphasizing the importance of S&T.

In this chapter, the research focuses on the patent outputs by looking into quantitative change and patent trends by Kim Jong-il and Kim Jong-un. The time period covers from 1999 to 2018, and the patents are analyzed by both the patent registration and application. Patent registrations are used for analyzing patents' number and trend by different government, and patent applications are used for a cross-national comparison to assess North Korea's patent outputs to that of other

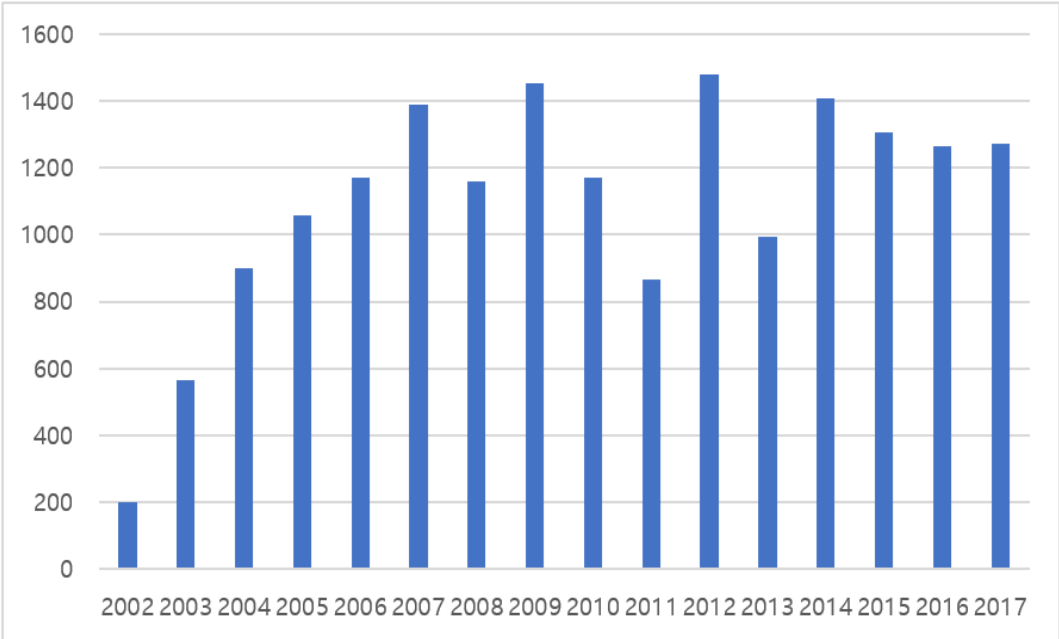
[18] Exception: 2016 and 2018

lower-middle-income states with a similar income scale.

2-1. Quantitative competitiveness of patent

The number of patent registrations in North Korea was as low as 201 in 2002 but the number dramatically increased to approximately 1,500 in 2009. The number seems stabilized maintaining an average of 1,000 patents for the next eight years. Although there has been a moderate increase and decrease in North Korean patent registration during the second half of Kim Jong-il's regime, North Korean patents today seem to maintain in roughly 1,000 patent registrations and 4,000 patent applications. The fact that there is no such sharp decline shown in the late Kim Jong-il to the Kim Jong-un's regime implies that the country have persisted its interest and support in fostering patents.

Figure 3. Changes in the number of patent registrations in North Korea



Source: DPRK Official Journal of Invention

Figure 3 illustrates a dramatic increase of North Korean patent registrations in the early era of Kim Jong-il. The number of patent registrations in the early of Kim Jong-il's rule was 201, but the number doubled to 565 in 2003 then jumped to 1,171 by 2006. There was a couple of moderate increase and decrease between 2006 and 2011 but the patent registration mostly stayed in between 1,000. The impressive increase in the number of patent registrations since 2002 was the result of the government's strong will to expand patent registrations despite its struggle in keeping the nation as a firm socialist state. First, the government came up with a legal mechanism and incentives that would increase computer-related patent registration in order to expand and reinforce the

comparative advantage in the IT industry along with the science-oriented policy. For example, in 2003, North Korea enacted the Computer Software Protection Act, Article 29 which "implemented a software copyright registration system, allowing intellectual property rights, such as copyrights, to be extended for the first 30 years, and up to 50 years." This was an unconventional decision hardly seen in socialist countries thereby demonstrates North Korea's willingness to increase its national power through the strategic development of the software industry (Ko, Lee, and Chang, 2007).[19] As a result, a number of computer-related patents were registered since 2002, gradually catching up with the number of human necessities related section of patents. Such improvement has indeed affected the number increased in the patent registration in the early years of the 2000s.

Kim Jong-il's national support for overseas patents also increased from the early 2000s where North Korean patents were filed into International Applications via WIPO Administered Treaties. In contrast to a total of three patents filed in the 1990s, the number of overseas patents were jumped to the total number of 13 in 2000s (KIPO, 56). Since applying for an overseas patent via WIPO requires a great

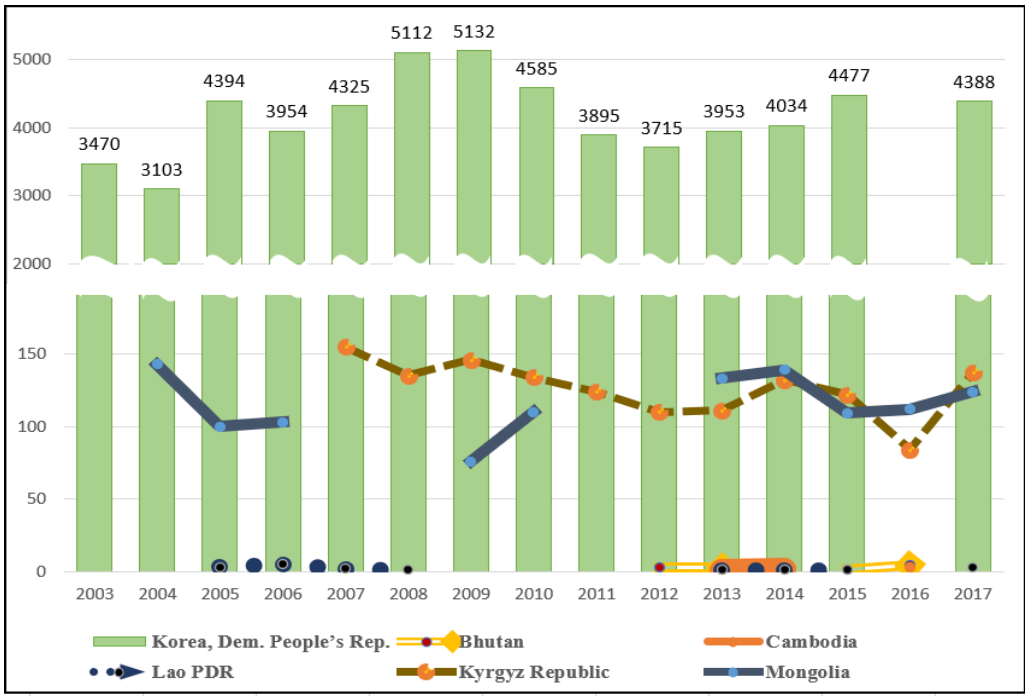
[19] Socialist countries in general lack providing incentives for individual creativity as invention rewards. For example, in the case of the former Soviet Union, the game programmer who created the game "Tetris" has not received any financial reward. Also, Mikhail Kalashnikov, the developer of the most commonly used gun AK-47 had no patent rights at the time since his right was attributed to the former Soviet Union (Nam, 2002). Therefore, it was Kim Jong-il's great interest and unconventional treatment that brought the emergence of the Computer Software Protection Act followed by the Software Industry Act in 2004.

deal of application fee, North Korea does not prefer to apply for an overseas patent if markets finding or the revenues are not guaranteed. In that sense, although this number cannot be seen as a large number, an incremental number of international patents by North Korea indicates that the country gives much attention to patent outputs despite the high cost of registration. Indeed, North Korea's patent outputs are lacking if compare to other advanced or high middle-income states, but its persistence over filing into overseas patent should not be neglected. For example, North Korea has a record of a total of 88 applications (23 PCTs and 57 Madrid dictum) and an annual average of 10 overseas applications over the last eight years of the current government.

On the other hand, patent application during Kim Jong-un's regime seems to maintain at least 1,000 of registration annually. This reflects his ambition on S&T innovation via the IRNC strategy which has led to maintaining a relatively high number of patents than other LMI states. While Kim Jong-il arranged institutional settings to encourage patents, Kim Jong-un strives to enlarge public awareness of patents by providing a platform where both intellectuals and the public can easily register their patents. One of the noteworthy cases is the "intellectual product exhibition" held in Pyeongyang every year since 2014 where people can promote and trade "intellectual products." North Korea seems to have set such a platform for helping people develop patents in order to promote the spread of inventions and patents based on science and technology. The exhibition

provides a service not limited to search for and register patents but also provides translation service for the technologies that applicants want to register. It also holds lectures and presentations on inventions and patents, contributing to enhance social awareness of "intellectual ownership" in Pyeongyang society. In other words, North Koreans, on one hand, have come to realize that they can only maximize their own interests by introducing the technology they have developed, and the state on the other hand has stepped up to give full support for the spread of patents. Since Kim Jong-un eagerly support fostering patents and the public become aware of a way to protect their own interest, the volume of transactions at the Pyongyang IP Center (PIPC), a company that helps register patents and trademarks, has also drawn much attention (Byun, 2018).

Figure 4. Changes in the number of patent application in LMI states



Source: DPRK Official Journal of Invention

Meanwhile, North Korea's patent outputs seem remarkable when its patent applications are compared to that of other LMI states in East Asia such as Bhutan, Cambodia, Lao PDR, the Kyrgyz Republic, and Mongolia. Although the Kyrgyz Republic and Cambodia have slightly higher GNI than North Korea and the rest have twice the higher GNI than the hermit state,[20] North Korea is producing far more patents than these countries. For example, the average number of patent applications of the Kyrgyz Republic by residents stayed approximately 126 patents

[20] According to data provided by the World Bank in 2019, North Korea recorded a GNI per capita of $1,156, followed by Kyrgyzstan ($1,120), Cambodia ($1,390), Bhutan ($2,970), Laos ($2,450), and Mongolia ($3,660).

per year between early 2004 and 2017, and Mongolia also has a similar average number of 115. Lao PDR, Cambodia, and Bhutan have hardly produced 10 patents per year for the same period. Similar results are seen in the case of international patent applications via WIPO. Aforementioned, North Korea since Kim Jong-il's regime consistently administered overseas patents regardless of its lower number compared to other middle-income states or advanced countries, and its effort is passed down to Kim Jong-un. Cambodia has only administered one patent under PCT systems and 11 by Madrid systems since 2010, and Bhutan has not administered a single overseas patent. Situations are better for Mongolia, Lao PDR, and the Kyrgyz Republic where they have produced a total of 36, 34, and 55 patent applications respectively via WIPO administered treaties. However, these numbers are still less than that of North Kore's total of 88 overseas patent applications via WIPO. Thus, North Korea's outstanding patent outputs, relative to its LMI peers shows the ambition of this socialist country's heavy investment and support in S&T innovation.

2-2. Patents by categories

North Korea joined WIPO in 1974 which means it follows the international patent classification provided by WIPO. Accordingly, the country's patents can be

categorized into eight types; A, B, C, D, E, F, G, and H.[21] This section compares patent trends between two governments on the basis of 21,040 patents mentioned in *DPRK Official Journal of Invention* from 1999 to 2018 and categorizes them by following international patent classification. This section does not compare the trends by the number of patents by each government as the number of patents introduced in each issue is not coherent. For example, the number of patents mentioned in the journal issued from 1999 to 2008 gradually decreased as the contents of patents was further supplemented. However, the number suddenly increased since 2009 as the journal changed into a monthly publication. Above all, it is not fair to compare the number of patents by sector by governments since Kim Jong-il had ruled for 13 years ever since he announced the S&T-oriented policy but Kim Jong-un ruled for only seven years until 2018. Instead, this section compares and analyzes patents by percentage, not by numbers, whether there has been a change of leading sector based on the eight types of classifications.

[21] A: Human Necessities
B: Performing operations, transporting
C: Chemistry, metallurgy
D: Textiles, paper
E: Fixed constructions
F: Mechanical engineering, lighting, heating, weapons
G: Physics
H: Electricity

Table 7. The composition of patents by different regimes

Kim Jong-il (1999-2011)		
A	2632	**22.41%**
B	1682	**14.32%**
C	2190	**18.64%**
D	296	**2.52%**
E	627	**5.34%**
F	732	**6.23%**
G	2339	**19.91%**
H	1249	**10.63%**

Kim Jong-un (2012~2018)		
A	1784	**19.20%**
B	1453	**15.64%**
C	1677	**18.05%**
D	231	**2.49%**
E	538	**5.79%**
F	596	**6.41%**
G	2266	**24.38%**
H	748	**8.05%**

Overall		
A	4416	**20.99%**
B	3135	**14.90%**
C	3867	**18.38%**
D	527	**2.50%**
E	1165	**5.54%**
F	1328	**6.31%**
G	4605	**21.89%**
H	1997	**9.49%**

Source: DPRK Official Journal of Invention

Table 8. The composition of patents by year

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
A	26.78%	27.85%	25.52%	26.81%	18.03%	26.42%	20.12%	20.06%	21.50%	30.25%
B	16.90%	15.66%	14.44%	13.14%	16.67%	17.25%	17.01%	12.12%	10.88%	11.61%
C	22.30%	23.42%	20.71%	27.08%	22.13%	15.66%	17.31%	15.60%	15.38%	17.12%
D	2.99%	5.06%	3.77%	2.14%	4.37%	4.43%	3.99%	1.67%	1.25%	1.29%
E	3.79%	3.32%	3.14%	1.34%	4.92%	3.96%	4.88%	3.06%	3.00%	5.28%
F	6.44%	4.43%	10.88%	5.36%	12.30%	5.54%	4.88%	6.82%	5.38%	5.63%
G	10.69%	9.34%	12.13%	15.01%	10.38%	16.77%	21.75%	27.30%	30.25%	16.18%
H	10.11%	10.92%	9.41%	9.12%	11.20%	9.97%	10.06%	13.37%	12.38%	12.66%

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
A	20.66%	19.32%	19.04%	17.32%	23.43%	16.98%	16.21%	20.89%	19.62%	19.95%
B	16.10%	13.61%	12.26%	15.05%	15.62%	17.89%	16.49%	13.17%	14.76%	17.27%
C	14.39%	18.10%	23.17%	14.97%	17.79%	16.68%	19.72%	18.22%	20.70%	18.39%
D	2.63%	1.80%	1.42%	2.82%	3.30%	1.82%	3.37%	1.93%	1.80%	2.42%
E	8.49%	6.74%	5.98%	6.11%	5.48%	7.43%	4.07%	6.87%	4.77%	5.35%
F	6.00%	6.23%	5.91%	6.03%	7.09%	7.05%	7.58%	5.73%	5.49%	5.87%
G	20.16%	24.01%	24.34%	28.61%	20.77%	25.47%	23.65%	24.29%	23.76%	24.01%
H	11.58%	10.21%	7.89%	9.09%	6.52%	6.67%	8.91%	8.91%	9.09%	6.74%

Source: DPRK Official Journal of Invention

According to the total distributions of North Korean patents from 1999 to 2018, physics was the highest; 21.89%, followed by human necessities(A), Chemistry and metallurgy(C), and performing operations and transporting (B). However, there has been a fluctuation among the leading sectors by each regime

and even within the same regime that reflect the transition in patent trends. During the Kim Jong-il's era, A was the most commonly registered type with the record of 22.41 % (2,632 cases) among the total of 1,1747 inventions mentioned in *DPRK Official Journal of Invention*, followed by G; 19.91% (2,239 cases) and C;18.64% (2,190 cases). Table 8 indicates that A was the leading sector in the early reign of Kim Jong-il but C emerged as a new leading sector overtaking its place of A in the year between 2002 and 2003. The significance of G also rose since 2004 competing against A. Although these C and G were commonly registered in the second half of Kim Jong-il's regime, A was mostly considered as the leading sector in patent registration by which means that North Korea during Kim Jong-il's regime were tilted to agriculture, food, medicine, and other daily necessities, as well as chemicals and metallurgical technologies. Meanwhile, sector B occupied the third-highest share next to A and C before the rise of G but its significance dropped to 12% in 2006 struggling to recover its position until Kim Jong-un comes into power.

On the other hand, according to the distributions of North Korean patents during Kim Jong-un's regime shown in table 7, Physics was the highest; 24.38% (2,266 cases) among the total of 9,293 patents mentioned in the journal, followed by A;19.20% (1,784 cases), C; 18.05% (1677 cases), and B; 15.64% (1453 cases). Unlike the previous regime where A, C, and G were competing against each other in the pursuit of the leading sector, sector G maintained its position as a leading sector in the current regime (exception: 2013). In addition, A, which used to be the

highest share has fallen below 20% since 2014. Since sector B covers engineering and technology, the patent increase in B along with G is expected to bring a positive effect on North Korea's production efficiency and S&T innovations.

In particular, it is worth to examine deeper into section G as it directly links to computer science by section. Patents registered as G01, G05, and G06 have commonly appeared in the journal during Kim Jong-il's regime in the following order of G01>G06>G05, and inventions under the category of G05 and G06 were frequently mentioned from the latter half of the Kim Jong-il's regime. G sections under Kim Jong-un's regime, in contrast, appeared in the order of G06>G01>G05 and G06, especially includes patents related to machine learning or computer programming such as "Pig Factory Computer Integrated Production System (KP64760H)," "Buried type robot controller (KP64728H)", "Intrusion fried rice board CNC system (KP64727H)", and "Computer-assisted shipboard design method (KP64169H)."

In short, the overall patent trends from Kim Jong-il to Kim Jong-un regimes show consistency with sector A, B, C, and G as the most commonly registered patents mentioned in *DPRK Official Journal of Invention*. In particular, the basic sciences known as the foundation for innovation growth are included in sector B, C, and G, and these fields have long been emphasized from the latter half of Kim Jong-il's regime to the current government. The share of B, C, and G during Kim Jong-il and Kim Jong-un's rule were 52.8% and 58.66% respectively,

comprised more than a half of the total patents described in the journal that implies the country has been emphasizing basic science for a relatively long time. The difference is the shares of sector A, B, C, and G by governments. Although C and G emerged as one of the new leading sectors, A kept its position as the most commonly registered patents over the previous regime whereas the proportion of A decreased to one level below than G and B in the current regime. Since B and G play a key role in technology, basic science, and computer science, the upsurge of these fields suggests the national promotion on the IRNC is also indirectly reflected in patent fields. In other words, if the number of patents represents the government's national support for science and technology, the increase in G, B, and C and decrease in A in the Kim Jong-un's regime may be the result of the country's selectivity in certain types of S&T fields.

V. Conclusion

This thesis investigates the transition and development of North Korea's S&T policy and its innovation outputs from Kim Jong-il's S&T-oriented policy to Kim Jong-un's IRNC. North Korea has consistently emphasized S&T development as the key to its economic development. The biggest difference between the past and current regime is that Kim Jong-il considered IT as a comparative advantage to

leapfrogging instantly from Industry 2.0 to Industry 3.0 whereas his son looks to implementing CNC as a new comparative advantage for augmenting diverse civilian industries, thereby improving the development of North Korea and achieving knowledge-economy. Kim Jong-il's S&T-oriented policy, however, was tilted towards recovering economic downturn by supplementing light industry; thus, no substantial contribution to its economy was ultimately made. It was not until Kim Jong-un's regime that the country's S&T capability remarkably improved via the IRNC compared to those of the previous regimes and even with those of other LMI states.

North Korea's innovation results were analyzed through comparisons between the past and the current government as well as those of other LMI countries, such as Bhutan, Cambodia, Mongolia, the Kyrgyz Republic, and Lao PDR. North Korea's dramatic increase in both independent and joint research indicates that Kim's IRNC, in the pursuit of knowledge-economy, is in progress with significant innovation actually being made this time. Also, its number of S&T journal publication not only surpassed Bhutan's in 2016, but Lao PDR's as well in 2018. Higher quality researches were also conducted under Kim Jong-un's regime under better R&D environments. In 2018, 20% of North Korea's SCI-level S&T articles were known as world-class, and 4% of its works was globally recognized. Furthermore, North Korea's innovation capability is surpassing that of other LMI states when it comes to patent application and registration. North Korea annually

maintains roughly 1,000 patent registrations and 4,000 patent applications since the late Kim Jong-il regime, whereas the Kyrgyz Republic and Mongolia remain at an average of 120s and with Lao PDR, Cambodia, and Bhutan hardly producing 10 patents annually for the same period. The same applies to the overseas patent application via WIPO administered treaties; when it comes to the patent by categories, the overall patent trends from the Kim Jong-il to Kim Jong-un regimes show sectors A, B, C, and G as the most commonly registered patents described within *DPRK Official Journal of Invention*. However, the upsurge of patents in sector G, B, and C and the downturn of sector A under Kim Jong-un's regime indicates to the government's further support on technology, basic science, and computer science.

The determination to pursue economic development through leapfrogging was passed down from Kim Jong-il to Kim Jong-un for reinterpretation, and this hermit country aspires to leap from the obsolete industry 3.0 to industry 4.0 and achieve greater economic outputs this time. Innovation achievements under the IRNC have shown consistent growth and have produced greater results than that of the previous regime as well as those of other LMI nations with similar economic scale. Accordingly, North Korea's S&T is considered to be obsolete only when compared to highly industrialized countries such as South Korea. North Korea's current S&T development may not be at the level of advanced countries, but it certainly has the potential to be placed as a late-innovator amongst other LMI

countries. Therefore, North Korea's IRNC strategy acts as the key to reinforcing its Industry 3.0 and leapfrogging into Industry 4.0. Such innovation outcomes suggest North Korea has the potential to leapfrog this time, and should it continue to follow this trend, the country may reach the upper LMI tier.

Marketisation and digitalization have fueled economic and social changes in North Korea in the twenty-first century. North Korea's market economy has been established via bottom-up social changes led by its rapidly spreading markets since the 1990s. Simultaneously, the S&T promotion policies eagerly adopted by both Kim Jong-il and Kim Jong-un have gradually permeated throughout the informal society. For instance, marketization and digitalization have produced an e-payment card system that has revolutionized the financial sector (Park, 2018), and recent trials of digitalizing manufacturing systems have helped initiate industry 4.0 in North Korea. This economic and social progress shows how the IRNC can be North Korea's future engine of economic development.

It is, however, too early to determine whether North Korea can achieve its final goal of becoming a strong and prosperous nation, since such a goal requires advanced marketization and technological cooperation between countries as a perquisite. Such a prerequisite can only be achieved through denuclearization. Kim's persistent pursuit of nuclear weapons and missile development hinders any possibility of further progress in other industrial sectors; should current policies persist, North Korea will not advance to become an economic powerhouse through

the IRNC. While the effects of sanctions on North Korea's economy cannot be fully measured, international isolation, the lack of delivery of necessary energy resources, limited overseas funding for research, and limited S&T cooperation amongst states will certainly impact North Korea's ability to pull its full weight behind the IRNC.

These limitations will eventually affect North Korea's long-term economic growth. The IRNC strategy that has been a priority of Kim Jong-un since 2012 has shown its potential to drive the country to advance further. However, the current regime's continued development of weapons of mass destruction and isolation from the international scene will limit its potential to achieve any significant economic growth. North Korea will advance its S&T rapidly when peace is established on the Korean peninsula, and only then can it be fully integrated into the world trading system. Therefore, while it is clear that the IRNC is the key to North Korea's leapfrogging, North Korea's success in achieving national development and global S&T partnerships depends on Kim Jong-un's decision to denuclearize.

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국문초록

북한은 넓게 해석하면 북한식 4차 산업혁명이라 볼 수 있는 새세기산업혁명을 증진하기 위해 상당한 노력을 기울이고 있다. 새세기산업혁명은 북한의 경제발전과 과학기술혁신을 목적으로 적극적으로 추진되어 왔다. 지속되는 경제 제제로 인해 자금난을 겪고 있으면서도 북한은 과학기술 혁신에 대한 중요성을 인지하고 위 전략을 통해 선진국 못지않은 열정으로 연구개발에 지원을 아끼지 않고 있다. 한편, 이 은둔 국가에 대한 선입견과 선진국의 과학기술혁신 수준을 기준으로 북한의 과학기술혁신이 평가되면서 북한의 과학기술은 여전히 매우 낙후된 것으로 평가되고 있다. 과연 북한의 과학기술은 낙후되었고 경제발전 수단으로 기대하지 못할 만큼 형편없는가? 본 논문은 김정일 정권부터 김정은 정권까지 북한 과학기술 정책의 변화와 발전을 살펴보고 이들의 과학기술혁신 역량을 분석한다. 이를 통해 새세기산업혁명을 통한 현 정권의 과학기술혁신이 이전 정권에서 미약했던 혁신 창출을 가속화했고 나아가 북한의 과학기술 역량이 북한에 비해 조금 우위에 있는 혹은 비슷한 산업발전단계에 있는 국가들과 비교했을 때 결코 뒤쳐지지 않음을 주장한다. 또한, 새세기산업혁명 전략이 북한 단번도약의 열쇠가 되는 잠재력을 지니고 있음을 강조한다. 그러나 현 정권의 지속되는 핵 개발 의지와 이에 따른 국제적 봉쇄로 인해 새세기산업혁명의 최종 목표인 사회주의 경제강국으로의 성공 전망은 회의적일 수밖에 없다. 따라서 북한이 비핵화를 선언하고 개혁개방을 통해 그들이 꿈꾸는 경제강국을 이룰지, 아니면 경제 회복과 중저소득국가수준에서 만족할 것인지는 김정은의 선택에 달려 있다.

주요어: 북한, 김정은, 새세기산업혁명, 과학기술, 경제발전
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