Assessing Intangible Technology Transfer in North Korea's Nuclear International Collaboration Networks

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Abstract

While the focus of nonproliferation efforts is often on controlling trade in physical goods, the transfer of intangible technology – non-physical knowledge, technical skills, software, and the like – is at the heart both of North Korea's proliferation efforts and United Nations sanctions attempting to hinder that proliferation. This article investigates how North Korea has attempted to acquire nuclear intangible technology for its development through its international research networks. Using a dataset of several thousand journal articles in nuclear-related fields, the authors conduct a network-based analysis to track the changes in the structure of North Korea's international scientific collaboration networks over a fifty-year period. The article finds that North Korea has pursued a multi-prong strategy to acquire nuclear intangible technology. First, it has adapted the geographic scope of its scientific collaborations in response to geopolitical and sanctions trends. Second, it has gradually integrated core nuclear research with engineering and related advanced scientific fields, allowing for a maturation of its technical capabilities. Third, it has coalesced a cluster of research institutions that are interconnected with each other and with foreign institutions, allowing for foreign importation and domestic integration of nuclear-related knowledge. The article findings have implications for strategic trade controls involving intangible technology transfer.

Keywords

Intangible technology transfer, nuclear, North Korea, sanctions, international collaboration

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1. Introduction

How has North Korea attempted to acquire intangible technology in furtherance of its nuclear enterprise? Part of any country's ability to create an indigenous nuclear sector, whether for civilian (energy, medical, industrial, and research) or for military (weapons or naval propulsion) purposes is the availability of knowledge from abroad, and the ability of the country's institutions and researchers to bring in that knowledge and integrate it into the country's processes for developing and operating different aspects of the nuclear sector.[2] Other countries often have their own reasons for sharing nuclear-related knowledge, which may be to encourage either the civilian energy sector, research collaboration opportunities or (rarely) nuclear weapons capacity.[3] There is some controversy as to whether countries that receive sensitive technical assistance are more likely to proceed with nuclear weapons programs or not, but if they do proceed with developing nuclear weapons, they may have consistent problems incorporating that foreign knowledge, often due to the authoritarian nature of the regime.[4,5,6]

Given the connection between nuclear energy and research, and potentially nuclear weapons development, much of the Nonproliferation Regime's focus has been on controlling the transfer of technology with potential civilian and military use. While much of that technology comes in the form of physical goods, the transfer of intangible technology – non-physical knowledge, technical skills, software, and the like – is also key in the development of a nuclear sector, whether civilian or military.[7] North Korea stands as the archetypal example of a country that has not only successfully used its status as a party to the Nonproliferation Treaty (NPT) to acquire physical goods and intangible technology for its nuclear program, but to also continue acquiring tangible and intangible technology even in the face of exit from the NPT, United Nations sanctions, and other multilateral attempts to isolate the country.

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2 Donald MacKenzie and Graham Spinardi, "Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons," *American Journal of Sociology,* Vol.101, No. 1 (July 1995), pp. 44-99.

3 Matthew Fuhrmann, "Taking a Walk on the Supply Side: The Determinants of Civilian Nuclear Cooperation," *Journal of Conflict Resolution* 53, No. 2 (2009), pp. 181-208.

4 Matthew Kroenig, "Importing the Bomb: Sensitive Nuclear Assistance and Nuclear Proliferation," *Journal of Conflict Resolution* Vol. 53, No. 2 (April 2009), pp. 161-80; Matthew Kroenig, "Exporting the Bomb: Why States Provide Sensitive Nuclear Assistance," *American Political Science Review* Vol. 103, No. 1, (February 2009), pp. 113-133; Matthew Fuhrmann, "Spreading Temptation: Proliferation and Peaceful Nuclear Cooperation Agreements," *International Security* Vol. 34, No. 1 (2009), pp. 7-41. But see Nicolas Miller, "Why Nuclear Energy Programs Rarely Lead to Proliferation," *International Security*, Vol. 42, No. 2, (Fall 2017), pp. 40–77.

5 Alexander H. Montgomery, "Stop Helping Me: When Nuclear Assistance Impedes Nuclear Programs," in *The Nuclear Renaissance and International Security*, eds. Adam N. Stulberg and Matthew Fuhrmann (Stanford, CA: Stanford University Press, 2013), pp. 177-202; Jacques EC Hymans, *Achieving Nuclear Ambitions: Scientists, Politicians, and Proliferation* (Cambridge: Cambridge University Press, 2012).

6 Malfrid Braut-Hegghammer, *Unclear Physics: Why Iraq and Libya Failed to Build Nuclear Weapons* (Ithaca and London: Cornell University Press, 2016); Christopher Way and Jessica LP Weeks, "Making it Personal: Regime Type and Nuclear Proliferation," *American Journal of Political Science*, Vol. 58, No. 3 (2014), pp. 705-19.

7 Ian J. Stewart, "The Contribution of Intangible Technology Controls in Controlling the Spread of Strategic Technologies," *Strategic Trade Review, Vol.* 1, No. 1 (2015), pp. 41-55.

This article investigates how North Korea has attempted to acquire nuclear intangible technology for its development. Using a dataset of several thousand journal articles in nuclear-related fields drawn from international databases, the authors conduct a network-based analysis to track the changes in the structure of North Korea's international scientific collaboration networks over fifty years. The article finds that North Korea has pursued a multi-prong strategy to acquire nuclear intangible technology. First, it has adapted the geographic scope of its scientific collaborations in response to geopolitical and sanctions trends. Second, it has gradually integrated core nuclear research with engineering and related advanced scientific fields, allowing for a maturation of its technical capabilities, and potentially an increase in its ability to assimilate intangible technology. Third, it has coalesced a cluster of individual researchers and research institutions that are interconnected with each other and with foreign researchers and institutions, allowing for foreign importation and domestic integration of nuclear-related knowledge. The article closes with a discussion of its findings and implications for the understanding of intangible technology transfer to potential proliferating states.

2. Context: United Nations Sanctions on Intangible Technology Transfer

North Korean efforts to acquire foreign technology take place in the context of a climate that is increasingly hostile to North Korean technological interaction with the rest of the world. While there is substantial literature on North Korea's efforts to buy and sell physical technology and goods, United Nations sanctions resolutions since 2009 have also progressively attempted to tighten restrictions on transferring knowledge to (or receiving knowledge from) North Korea about any scientific, engineering, or other field that could be used to build Weapons of Mass Destruction (WMD) or the means to deliver them.[8] In effect, these resolutions limit the extent to which countries (or institutions within countries) can engage in scientific exchange with, or training or funding for, North Korean scientists on topics related to WMD or delivery systems.

United Nations Security Council resolution 1540 (2004) obliges UN Member States to regulate and control the export of technology that could be used to build WMD or their means of delivery to end-users or end-uses of concern so as to weed out illicit trade in these items to non-state actors.[9] In implement resolution 1540, countries may want to create and implement a strategic trade control regime, which is generally focused on the transfer of physical goods and technology to state and non-state actors alike.

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8 Justin V. Hastings, *A Most Enterprising Country: North Korea in the Global Economy* (Ithaca and London: Cornell University Press, 2016); Hazel Smith, *North Korean Shipping: A Potential for WMD Proliferation?*, East-West Center (Honolulu, HI, February 2009); Sue Eckert and Thomas Biersteker, *The Impacts And Effectiveness Of UN Nonproliferation Sanctions: A Provisional Report on the Targeted Sanctions on Iran and North Korea*, International Security Research and Outreach Programme, International Security and Intelligence Bureau (Ottawa, 2012); David Albright et al., *Illicit Trade Networks Connecting the Dots: Characterizing and Drawing Lessons from Tactics and Methods of Illicit Procurement to Improve Counterproliferation*, Institute for Science and International Security (Washington, DC, 2020); Sheena Chestnut, "Illicit Activity and Proliferation: North Korean Smuggling Networks," *International Security,* Vol. 32, No. 1 (2007), pp. 80-111.

9 "UN Security Council Resolution 1540," Department of State, Washington, DC, <http://www.state.gov/t/isn/c18943.htm>.

The United Nations Security Council has prohibited intangible technology transfer to (or from) North Korea with increasing specificity since 2006's passage of resolution 1718. In addition to banning the transfer to or from North Korea of tangible WMD- or missile-related goods, resolution 1718 banned "technical training, advice, services or assistance related to the provision, manufacture, maintenance or use of" large-scale weapons systems and technology "which could contribute to DPRK's nuclear-related, ballistic missile-related or other weapons of mass destruction- related programmes."[10] Resolution 2270 (2016) further required that:

> *"…all Member States shall prevent specialized teaching or training of DPRK nationals within their territories or by their nationals of disciplines which could contribute to the DPRK's proliferation sensitive nuclear activities or the development of nuclear weapon delivery systems, including teaching or training in advanced physics, advanced computer simulation and related computer sciences, geospatial navigation, nuclear engineering, aerospace engineering, aeronautical engineering and related disciplines."*[11]

Resolution 2321 (2016) clarified that the ban on training North Koreans in proliferation-sensitive activities included, but was not limited to "advanced materials science, advanced chemical engineering, advanced mechanical engineering, advanced electrical engineering and advanced industrial engineering." While medical exchanges and scientific and technical cooperation that was determined by enforcing states not to contribute to sensitive nuclear or ballistic missile activities was allowed, in three topic areas -- "nuclear science and technology, aerospace and aeronautical engineering and technology, and advanced manufacturing production techniques and methods" -- the UN 1718 Committee was to determine on a case-by-case basis whether the exchanges contributed to proliferation-sensitive nuclear or ballistic missile activities.[12]

Resolutions 2371 (2017), 2375 (2017), and 2397 (2017) limited and then banned DPRK nationals from earning income abroad, and urged their repatriation to North Korea.[13] While this was generally intended to cut off the North Korean state from the income earned by laborers abroad (such as loggers in Russia, waitresses in China, or construction workers in the Middle East), in theory this also had an effect on North Korean researchers earning a salary working in labs or universities outside North Korea. Resolution 2375 also prohibited joint ventures with North Korea (except for Chinese and Russian infrastructure projects), which can have the effect of minimizing opportunities for technology transfer (intangible or otherwise).[14]

In addition to these sanctions, designated individuals and entities are specifically sanctioned by the United Nations. Most sanctioned individuals are businesspeople engaged in trade, or military, Party, or civilian government officials who manage North Korea's WMD and missile

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10 United Nations Security Council Resolution 1718, S/RES/1718 (2006), October 2006.

11 United Nations Security Council Resolution 2270, S/RES/2270 (2016), March 2016.

12 United Nations Security Council Resolution 2321, S/RES/2321 (2016), November 2016.

13 United Nations Security Council Resolution 2371, S/RES/2371 (2017), August 2017; United Nations Security Council Resolution 2321, S/RES/2375 (2017), September 2017; United Nations Security Council Resolution 2397, S/RES/2397 (2017), December 2017.

14 United Nations Security Council Resolution 2375, S/RES/2375 (2017), September 2017.

programs, or who manage North Korea's efforts to bypass sanctions. They are not generally scientists. Of those most closely related to scientific research, Ri Hong-sop, for instance, was sanctioned as the former director of Yongbyon Nuclear Research Center, where he managed the fuel fabrication facility, the reprocessing plant, and the reactor itself.[15] Hwang Sok-kwa was sanctioned as the director of the General Bureau of Atomic Energy (GBAE), which managed Yongbyon Nuclear Research Center. Hwang was also chief of the Scientific Guidance Bureau for the GBAE and worked on the Scientific Committee in the Joint Institute for Nuclear Research.

Most sanctioned organizations are either trading companies or civilian government and military agencies charged with overseeing the trade of banned items or developing WMDs and missile systems. No university or non-nuclear, non-weapons research lab has been designated to date. Instead, among organizations engaged in nuclear or weapons research, the General Bureau of Atomic Energy, Korean Committee for Space Technology, Second Academy of Natural Sciences, Ministry of Atomic Energy Industry (the successor umbrella organization for the GBAE, with oversight over Yongbyon as well as various scientific committees, including the Isotope Application Committee), Academy of National Defense Science, and National Aerospace Development Administration have all been designated.[16]

3. How to Transfer Intangible Technology

In Stewart's discussion of intangible technology transfer, proliferation, and export controls, he posits the capability acquisition model (CAM), which suggests what it would take for a country to reach a target capability (in this case, a capability relevant to proliferation) through indigenization rather than through generation of genuinely new knowledge.[17] While the country would need materials and equipment (which are typically targeted by export controls), it would also need explicit knowledge –easily communicable information about technology – and tacit knowledge – the difficult-to-communicate information that is gained from experience and trial and error, and that is necessary to make the equipment work properly. This knowledge is difficult to transfer – institutional roadblocks to internal cooperation and knowledge transfer have delayed bioweapons and nuclear programs in the past.[18] All are necessary for North Korea (or any other proliferating country seeking an indigenous capacity) to build nuclear weapons.

This leads to the question of *how* intangible technology is transferred to North Korea. There are a number of pathways that would be relevant to North Korea's nuclear-related science and

15 "United Nations Security Council Consolidated List," United Nations, New York, 2022, <https://www.un.org/securitycouncil/content/un-sc-consolidated-list>.

16 Ibid.

17 Ian J. Stewart, "The Contribution of Intangible Technology Controls in Controlling the Spread of Strategic Technologies," *Strategic Trade Review, Vol.* 1, No. 1 (2015), pp. 41-55.

18 Sonia Ben Ouagrham-Gormley, *Barriers to Bioweapons: The Challenges of Expertise and Organization for Weapons Development* (Ithaca: Cornell University Press, 2014); Gaurav Kampani, "New Delhi's Long Journey: How Secrecy and Institutional Roadblocks Delayed India's Weaponization," *International Security*, Vol. 38, No. 4 (Spring 2014) pp. 79–114.

technology programs. First, North Korea may attempt to obtain intangible technology (both tacit and explicit knowledge) through straightforward espionage. In June 2012, for example, two North Korean operatives named Ryu and Ri were arrested by Ukrainian security services in the act of taking delivery of photographs of missile technology, obtained from the Yuzhnoye Design Office, the Ukrainian state-owned ballistic missile manufacturer.[19] This route was always illegal in the sense that all espionage is illegal. However, it may be further hampered by sanctions that limit the movements of North Korean citizens outside of North Korea.

Second, organizations might enter into technology transfer agreements, either in terms of licensing foreign technology for local production, or, second, in terms of joint venture cooperation. In joint ventures, technology may be consciously shared with North Korean partners, or the North Korean partners may use the joint venture's activities to learn how to use and potentially reverse engineer the technology. From this perspective, intangible technology transfer may occur almost accidentally, as North Koreans "learn by doing," through their interactions with joint venture partners (almost always Chinese) and by observing what the joint venture partners are doing. In some cases, this accidental intangible technology transfer puts joint venture partners at a disadvantage – in one particularly prominent case, the Chinese company Haicheng Xiyang built a factory in the North Korean city of Ongjin, and started processing iron ore powder in a joint venture with North Korean partners in April 2011. Within six months, the North Koreans had learned how to run the equipment and process the iron ore powder, and began squeezing the Chinese investors, eventually expropriating the factory and expelling them entirely six months after that.[20]

A number of Chinese businesses, conscious of this tendency to steal both tangible and intangible technology, have taken steps in their joint ventures to minimize the ability of North Korean partners to expropriate their technology. Examples would include using only Chinese workers (in North Korea) for skilled service provision, such as in automobile repair, exporting only unprocessed goods from North Korea (meaning that the processing facilities, and their technologies, are outside of North Korea), and using advanced equipment inside North Korea (in construction, for instance) that only foreign workers are allowed to operate, minimizing the benefits that North Koreans would derive from expropriating.[21] With UN sanctions on new joint ventures, this avenue for North Korean intangible technology transfer may also be closing.

Third, North Korean researchers might attend technical exchanges, training workshops, or conferences, either held with international researchers inside North Korea, or held outside of North Korea. Indeed, exchanges and collaboration were often broached during periods of high

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19 "Report of the Panel of Experts Established Pursuant to Resolution 1874," United Nations Security Council Panel of Experts, United Nations Security Council, New York, April 2009.

20 "Xiyang Jituan zai Chaozian Touzi de Emeng," Sina.com.cn, August 3, 2012, <http://blog.sina.com.cn/s/blog_916fb56901017b75.html>; "Xiyang Jituan Touzi Chaoxian Lingmeikuang Shimo," *21st Century Business Herald*, August 17, 2012; "Xiyang jituan 2.4 yi touzi Chaoxian: Zhou Furen zishu "beitao" shimo," *21st Century Business Herald* (Guangzhou) August 25, 2012.

21 Justin V. Hastings and Yaohui Wang, "Informal Trade Along the China-North Korea Border," *Journal of East Asian Studies,* Vol. 18, No. 2 (2018), pp. 181-203; Justin V. Hastings and Yaohui Wang, "Chinese Firms' Troubled Relationship with Market Transformation in North Korea," *Asian Survey*, Vol. 57, No. 4 (2017), pp. 618-40.

engagement between North Korea and outsiders as a way of sharing knowledge and building relationships among researchers.[22] Particularly in dual-use science and technology fields, these types of exchanges have long been banned by UN sanctions, so they are unlikely to be a major source of new intangible technology transfer.[23]

Finally, North Korean researchers may engage in academic research collaboration with outside researchers. North Korean student researchers, for example, might study outside of North Korea (usually in China), and acquire knowledge through working in the labs of local researchers. North Korean researchers may also engage in research collaborations with foreign labs and institutes, with the resulting co-authored publications indicating that some technological know-how was likely transferred. These types of collaborations are the ones that may be a valuable means of intangible technology transfer, inasmuch as they inherently require repeated interactions, sharing between researchers of data, methods, results, and technology, and some amount of complementary effort. As a result, this paper will focus on North Korea's international co-authoring efforts as a means of intangible technology transfer.

Nonaka and Takeuchi discuss the process of transferring tacit knowledge, explicit knowledge, tacit knowledge to explicit knowledge, and explicit knowledge to tacit knowledge.[24] Crucially, co-authoring on scientific journal articles potentially involves several elements of Nonaka's innovation cycle: co-authors may transfer tacit knowledge between each other due to social interaction on an ongoing basis in a form of socialisation. Conducting research and writing up the research may allow for transfer of explicit knowledge to tacit knowledge -- integration. The co-authors' interaction would also involve sending information among each via email and other means, in an example of combination. Finally, the scientific journal articles themselves are designed to create and transfer explicit knowledge – the technical data that in theory should allow readers to replicate the research, although not always successfully.

4. North Korea's International Scientific Research Collaborations

In the past two decades under both Kim Jong-un and his predecessor Kim Jong-il, North Korean researchers have been increasingly encouraged to publish in international scientific journals, which often requires international collaboration, partly as a way to build up indigenous knowledge and decrease dependence on importation of knowledge or goods.[25]

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22 C. Campbell, "A Consortium Model for Science Engagement: Lessons From the US-DPRK Experience," *Science & Diplomacy*, No. 1 (2012); R. D. Shelton and G. Lewison, "Scientific Collaboration as a Window and a Door into North Korea," *Scientometrics,* No. 97 (2013), <https://doi.org/10.1007/s11192-012-0946-8, https://doi.org/10.1007/s11192-012-0946-8>.

23 Non-scientific exchanges and training have not been banned, which is why business training programs run by foreign groups were able to continue operating inside North Korea, at least until the Covid-19 restrictions began in January 2020.

24 Ikujiro Nonaka and Takeuchi Hirotaka, *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation* (New York: Oxford University Press, 1995).

25 Joshua H. Pollack and Scott LaFoy, *North Korea's International Scientific Collaborations: Their Scope, Scale, and Potential Dual-Use and Military Significance*, Center for Nonproliferation Studies (Washington, DC, 2018).

These international collaboration efforts, often in the face of increasing sanctions, have been studied by a number of researchers who have sought to answer a series of related questions.

First, in which disciplines and on what topics are North Koreans collaborating with international researchers? North Korean researchers do engage in international collaboration on proliferation- or weapons-sensitive topics, although unsurprisingly, most research is on more mundane scientific topics. Dual-use technology-relevant areas, with computer science, engineering, mathematics, and physics are the most prominent areas of collaboration since Kim Jong-un came to power.[26] Pollack and LaFoy find that there are indeed a small number of international collaborations on topics of proliferation interest up to 2018, mostly with Chinese collaborators. For example, research papers regarding cables that can be used in nuclear power plants, possible missile technologies (e.g., satellite-imaging, remote sensing), and carbon composites that are applicable to an advanced gas centrifuge for uranium enrichment were published by Chinese scholars in collaboration with North Korean scientists.[27]

Second, with *whom* are North Korean researchers collaborating? Generally, studies have found that North Korean researchers collaborate with Chinese researchers, often by affiliating with Chinese institutions, and to a lesser extent with Germans.[28] This may well be in line with China's engagement strategy with North Korea, inasmuch as it encourages communication and trade between North Korea and China, particularly in the regions of China bordering North Korea.[29]

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26 Kyung-Ran Noh, Eun-Jeong Kim, and Hyun-Kyoo Choi, "A Study on the Production of Science and Technology Knowledge in North Korea through International Academic Papers," *Journal of the Korean Biblia Society for Library and Information Science* 27, No. 4 (2016), pp. 205-27.

27 Joshua H. Pollack and Scott LaFoy, *North Korea's International Scientific Collaborations: Their Scope, Scale, and Potential Dual-Use and Military Significance*, Center for Nonproliferation Studies (Washington, DC, 2018).

28 Han Woo Park, and Jungwon Yoon, "Structural Characteristics of Institutional Collaboration in North Korea Analyzed through Domestic Publications," *Scientometrics*, Vol. 119, No. 2 (2019), pp. 771-787; Yoo-Seong Song, "A Glimpse into Academic and Research Libraries in North Korea: Collaboration to Bridge Societies," *College & Research Libraries News,* Vol. 80, No. 2 (2019), p. 82; Joshua H. Pollack and Scott LaFoy, *North Korea's International Scientific Collaborations: Their Scope, Scale, and Potential Dual-Use and Military Significance*, Center for Nonproliferation Studies (Washington, DC, 2018); Hyun-Kyoo Choi and Yeong-Sil Kang, *Current Status of Research Institute for Science and Technology in North Korea* (Daejeon, Republic of Korea: Korea Institute of Science and Technology Information, June 2017); Geum Hee Jeong, and Sun Huh, "Update: Bibliometric Analysis of Publications from North Korea Indexed in the Web of Science Core Collection from 1978 to July 2018," *Science Editing*, Vol. 5, No. 2 (2018), pp. 119-123; Geum Hee Jeong and Sun Huh, "Bibliometric and Content Analysis of Medical Articles in the PubMed Database Published by North Korean Authors from 1997 to July 2017," S*cience Editing*, Vol. 4, No. 2 (2017), pp. 70-75.

29 Tat Yan Kong, "China's Engagement-Oriented Strategy towards North Korea: Achievements and Limitations," *The Pacific Review*, Vol. 31, No. 1 (2018), pp. 76-95; Wenzhi Song and Sangkeun Lee, "China's Engagement Patterns towards North Korea," *Pacific Focus*, Vol. 31, No. 1 (2016), pp. 5-30; James Reilly, "China's Economic Engagement in North Korea," *China Quarterly*, No. 220 (2014), pp. 915-35; Seung-Hyun Yoon and Seung-Ook Lee, "From Old Comrades to New Partnerships: Dynamic Development of Economic Relations between China and North Korea," *The Geographical Journal*, Vol. 179, No. 1 (2013), pp. 19-31, <https://doi.org/10.1111/j.1475-4959.2012.00474.x>.

Third, *how* are the North Koreans involved in collaborative research? Because they are short of funds (and presumably expensive equipment) but have a large supply of educated researchers, North Korean science teams tend to collaborate with international researchers on projects where the North Korean side can provide marginal benefit through intense labour (that is, North Korea provides the grunt work) and that have civil-military dual-use applications.[30] Their actual contribution to international scientific research is marginal and, while the quantity of research outputs has grown significantly under Kim Jong-un, it was starting from a low baseline.[31]

Analysis of an international journal article dataset from SCOPUS between 2007 and 2016 shows that, of North Korean scientists who published articles while staying at overseas institutions, there were 62 people from 24 institutions in the Kim Jong-Il period (through 2011), while about 150 people from 33 institutions were sent to overseas institutes in the Kim Jung-un period (from 2012).[32] It is also presumed that North Korean scientists who are affiliated with both North Korea and other countries might have been dispatched from their North Korean institutes to overseas institutes. North Korea collaborated frequently with China and Germany, but since 2012, most of the cooperation was with China. Specifically, the top Chinese organizations that published international journal articles with North Korea are Northeastern University and Jilin University (both in northeastern China near North Korea), the Chinese Academy of Sciences (in Beijing), and Zhejiang University (in southeastern China). In the Kim Jong-un period, Harbin Institute of Technology (in northeastern China near North Korea), Nankai University, Nanjing University, and Tsinghua University (all outside of northeastern China) emerged as new international cooperation institutions.[33] Thus, while most of North Korea's collaboration with foreign institutions was with Chinese universities in the northeastern border areas with North Korea, it shows an ability to branch out geographically, particularly as time went by.

At the same time, the political context in which international collaboration takes place has deteriorated considerably in the past ten years, since a previous flurry of articles on potential collaboration with North Koreans as a form of engagement.[34] Since United Nations sanctions began in 2009, it has become increasingly difficult for North Korean researchers to collaborate with international researchers for several reasons. First, international travel by North Koreans

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30 Eungi Kim and Eun Sil Kim, "A Critical Examination of International Research Conducted by North Korean Authors: Increasing Trends of Collaborative Research between China and North Korea," *Scientometrics, No.* 124 (2020), pp. 429-50.

31 Geum Hee Jeong, and Sun Huh, "Update: Bibliometric Analysis of Publications from North Korea Indexed in the Web of Science Core Collection from 1978 to July 2018," *Science Editing*, Vol. 5, No. 2 (2018), pp. 119-123; Geum Hee Jeong and Sun Huh, "Bibliometric and Content Analysis of Medical Articles in the PubMed Database Published by North Korean Authors from 1997 to July 2017," S*cience Editing*, Vol. 4, No. 2 (2017), pp. 70-75.

32 Hyun-Kyoo Choi and Gyung-Ran Noh, *Analysis of International Scientific Journal Articles (SCOPUS) by North Korean Scientists: 2007-2016* (Daejeon, Republic of Korea: Korea Institute of Science and Technology Information, September 2017).

33 Ibid.

34 C. Campbell, "A Consortium Model for Science Engagement: Lessons From the US-DPRK Experience," *Science & Diplomacy*, No. 1 (2012); R. D. Shelton and G. Lewison, "Scientific Collaboration as a Window and a Door into North Korea," *Scientometrics,* No. 97 (2013), <https://doi.org/10.1007/s11192-012-0946-8, https://doi.org/10.1007/s11192-012-0946-8>.

is limited by sanctions (or at least countries that are enforcing sanctions). Second, there are bans on providing technical training or technical assistance to North Koreans that could be used in developing weapons, or to North Korean groups that could be involved in WMD development. In practice, this makes collaboration on most types of science or engineering projects difficult. Third, for research that requires funding from outside of North Korea, actually transferring funds from research grants into North Korea is very difficult, due to restrictions on banking with North Korean institutions, and on giving money to North Korea for anything besides humanitarian aid.

The final question is what North Koreans are getting out of these international collaborations. Here the question of intangible technology transfer arises. Scientific co-authoring can itself be seen as a form of communication that confers certain benefits on the co-authors. Through (often repeatedly) interacting on a specific research project, collaborators can transfer tacit knowledge among each other. By necessity, a research team working on a project must engage in significant back-and-forth technical communication. Even research projects where the specific tasks (and knowledge about how to engage in those tasks) are neatly bifurcated and siloed require communication about the overall direction of the project, what each research team will contribute, and the purpose of each task.

This may not, as Stewart points out, directly lead to know-how about how to engage in industrial production of materials and equipment, given how specific (and often theoretical) much academic research is[35] However, depending on their location, North Korean collaborators may also have the opportunity to work on equipment and study techniques that they would not otherwise have had access to within North Korea – this would be most evident in North Korean students and researchers who leave North Korea to study, or take up visiting researcher positions in foreign universities (usually, as above, Chinese universities). There are fewer opportunities to work on new equipment for North Korean collaborators who remain in North Korea and engage in virtual collaboration with foreign collaborators.

In addition, given the repeated interactions of researchers across multiple research topics, individual researchers may transfer tacit knowledge to other people in North Korea and can bring in know-how from other researchers and research topics to improve their understanding of technology. In effect, North Korean researchers that engage in extensive international collaboration may be able to serve as conduits for tacit knowledge into North Korea.

6. Data and Methods

Data

This paper draws on a dataset of 1,286 journal articles written between 1974 and 2018 involving publications by North Koreans in international journals, and publications involving

35 Ian J. Stewart, "The Contribution of Intangible Technology Controls in Controlling the Spread of Strategic Technologies," *Strategic Trade Review, Vol.* 1, No. 1 (2015), pp. 41-55.

collaborations between North Korean researchers and non-North Korean researchers in nuclear science (specifically nuclear physics, plasma physics, and nuclear engineering) and related fields, specifically radiation, isotopic separation, physics, chemistry, engineering, materials science, mathematics, and computer science. While some of these fields, particularly mathematics and computer science, are potentially only tangentially related to a nuclear program, they are useful in helping us understand how North Korea transfers knowledge across a range of scientific research categories. The journal articles were collected from non-North Korean journals indexed on Scopus, Web of Science, and CNKI (for Chinese journals). While there is a separate dataset of North Korean domestic journals, there are no known international collaborative papers published in North Korean journals.[36] However, the next section tracks the North Korean authors who publish in both domestic and international journals.

Network Analysis

A given researcher in this methodology comprises the primary node in the collaboration network. The primary link codes is thus between two researchers who have co-authored a scientific paper together, with the width of the link representing the number of papers co-authored together. Research interaction that produces a published paper, particularly repeated interaction across multiple papers, is the primary means by which, we assume (for the purposes of this paper), that intangible technology is transferred from foreign researchers to North Koreans, and among North Koreans. In different network diagrams, besides the researchers, we also create links and nodes for: 1) the *categories* of research into which the paper falls; 2) the *countries* in which researchers were located; and 3) the *organizations* with which researchers were affiliated, where known. Thus, researchers were linked to their organizations (which formed their own node), and their countries (which also formed their own node).[37]

For networks with country nodes and links, we can see the countries where North Korean researchers are seeking to establish research ties, the density of those ties, and how this changes over time, possibly in response to sanctions, the availability of knowledge in different countries, or the willingness of countries to work with North Koreans. Greater density of ties with a given country would indicate that North Korea is relying on ties with researchers in that country; the relative density of ties relative to other countries indicates the extent of dependence on a given country.

For networks with research category nodes, we can see the extent to which working on papers within the same categories is creating clusters or linking otherwise unconnected researchers, which would indicate the existence of parallel research teams working on the same topics but not actually interacting. This would indicate siloing or duplication of effort. We can also see concentrations of research on certain topics, indicating the maturation and increasing focus on a given category as a matter of international collaboration, as well as the connections (and

36 Philip Baxter, Justin V. Hastings, Philseo Kim, and Man-sung Yim, "Mapping the Development of North Korea's Domestic Nuclear Research Networks," *Review of Policy Research*, Vol. 39, Issue 2 (2021).

37 This categorization is self-reported by authors. "Nuclear" is not its own separate category but is included as a connected category. It has sub-categories of plasma physics, nuclear physics, and nuclear engineering.

the density of those connections) between different research topics. This can indicate to us the extent to which research teams are interacting with other research teams. Greater interaction can lead to an integration and maturation of a research area. Increasing interaction between nuclear research teams and engineering research teams, for example, could indicate attempts to transition from basic to applied research, and build and operate nuclear-related equipment.

Likewise, for networks with organisation nodes, we can see not only where the researchers with different network roles are located and which organisations are most active in promoting relevant research, but also the extent to which the organisations, rather than individuals, are connecting different research categories and individuals. If organisations serve as the brokers, connecting different researchers and institutions, this could indicate siloing and potential difficulties in knowledge transfer. This is because if two researchers in the same category are linked by one or more organisations, but not by co-authoring or other researchers, this means there are multiple research teams working on a topic but communicating directly. If researchers are able to establish personal links outside of their organisations, this would integrate a growing research community capable of person-to-person knowledge transfer.

Time Periods

In order to track the evolution of the structure of North Korea's intangible technology transfer networks, we compare the networks across three time periods separated by major milestones in North Korea's nuclear program – 1974 to 1994, the year of the Agreed Framework; 1995 to 2006, when North Korea conducted its first nuclear test, and 2006 to 2018, when North Korea proclaimed that it had accomplished its nuclear deterrent objectives. We would expect different patterns of international collaborations in each time period based on the international environment faced by North Korea and the state of its indigenous capabilities. North Korea began its nuclear research program in the 1970s after receiving a research reactor from the Soviet Union, which began operating in 1965. From then until the end of the Cold War, North Korea built its nuclear research program, including a fuel rod fabrication plant and a uranium ore processing facility, largely at Yongbyon Nuclear Research Center, with help from Soviet and Chinese technicians, and engaged in research collaboration with other countries in the Communist Bloc.

However, the Soviets and Chinese grew suspicious of North Korean intentions and eventually withdrew their technical advisers, leaving North Korea to attempt to indigenize its program, and seek out technology, both tangible and intangible, on its own.[38] The first Korean Peninsula nuclear crisis began in 1993 when North Korea, having been pressured by China and the Soviet Union to join to the Nonproliferation Treaty, showed non-compliance with safeguards inspections and announced its intention to withdraw from the NPT.

The first major milestone, the Agreed Framework, signed in 1994 by the United States and North Korea, ended the first Korean Peninsula nuclear crisis. Under the framework, the U.S. agreed to

38 "China Withdrew the Experts in Nuclear Technology Deployed to North Korea," *Chosun Ilbo* (Seoul), September 8, 1992.

provide fuel oil and two 1000MW light water nuclear reactors to North Korea in exchange for North Korea shutting down and eventually dismantling its 5 MW graphite-moderated research reactor as well as freezing construction of two new graphite-moderated research reactors and pausing its withdrawal from the NPT.[39] During the period after the Agreed Framework, North Korean officially remained in the NPT and there were no United Nations sanctions on transferring intangible technology to North Korea.

With the collapse of the Agreed Framework by 2003 in the face of slow progress on building the light water reactors and an apparent confession by North Korea that it had begun enriching uranium using centrifuge technology, the United States and North Korea adopted increasingly confrontational stances. This eventually culminated in the second major milestone, North Korea's first (possibly fizzled) nuclear weapons test, on October 9, 2006. Over the next 11 years, North Korean nuclear weapons and missile tests alternated with increasingly onerous United Nations and unilateral sanctions, including those designed to inhibit intangible technology transfer. Finally, North Korea proclaimed in 2018 that it had accomplished its nuclear goals and was switching to focus primarily on economic development, ostensibly signalling the formal end of its need for foreign intangible technology transfer in nuclear-related fields.[40]

7. Patterns of Intangible Technology Transfer

Previous work has found that North Korea has sought to evade sanctions or more generally avoid strategic trade controls (of physical goods and technology) or scrutiny of its businesses through a series of interlocking strategies, including obfuscating the involvement of North Korea or North Koreans in international transactions, structuring North Korea's supply chain to appear legitimate for as much of the chain as possible, strategically choosing countries as suppliers or transit points with an optimal level of technological sophistication and trade linkages relative to willingness or ability to enforce sanctions and strategic trade controls, and straightforward smuggling.[41]

These strategies have generally led North Korea's sanctions and trade control-busting networks to be structured in certain ways outside of North Korea. While North Korea uses a series of front companies incorporated in a variety of countries, genuine third-country firms and individuals do much of the logistical and administrative work surrounding moving goods to and from the North Korean land and sea borders with the rest of the world, meaning that North Korea solves many of its strategic trade control-related challenges by not solving them at all. North Korea also prefers to use countries, particularly for brokering activities and as transhipment points,

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39 Jonathan D. Pollack, "The United States, North Korea, and the End of the Agreed Framework," *Naval War College Review*, Vol. 56, No. 3 (2003), pp. 10-50.

40 "Chairman of the KWP Kim Jung-un Proudly Declared Great Victory of Byungjin Line and Proposed a New Strategic Line for the Party [*jo-seon-lo-dong-dang wi-won-jang gim-jeong-eun-dong-ji-kke-seo byeong-jin-lo-seon-ui wi-dae-han seung-li-leul geung-ji-nop-i seon-eon-ha-si-go dang-ui sae-lo-un jeon-lyag-jeog lo-seon-eul je-si-ha-si-yeoss-da*]," *Korean Central New Agency (KCNA)*, April 21, 2018.

41 Justin V. Hastings, *A Most Enterprising Country: North Korea in the Global Economy* (Ithaca and London: Cornell University Press, 2016); Justin V. Hastings, "North Korean Trade Networks under Sanctions and Implications for Denuclearization," *Asia and the Global Economy* (forthcoming).

that are geographically proximate to North Korea and may have political or capacity reasons why they may not enforce sanctions or strategic trade controls rigorously.[42]

The sanctions evasion strategies have an analogue in how North Korea's international knowledge transfer networks have come to be structured over the last several decades. First, as discussed above, North Korean researchers have often obfuscated their nationalities and affiliations through arranging for affiliations at (usually) Chinese research institutions, and using the Pinyin transliterations of their Korean names, making them appear in the first instance to be Chinese researchers.

Second, while the specific scientific topics cannot be obfuscated (inasmuch as they are published in refereed international scientific journals), and many of the topics covered by North Korean international collaboration are not strategic *per se* (in that they are not directly applicable to CBRN or missile programs), the "legitimate" non-strategic collaboration networks help North Korea's research community build knowledge in fields – physics, nuclear engineering, chemistry, and the like -- that can improve the general level of North Korean scientific research as well as the intangible technology North Korea is able to acquire. North Korea has developed an increasingly dense research community, with researcher interactions across research categories and institutions, which could provide it with knowledge in areas that may be useful as it builds its overall capacity, including in nuclear research.

Third, over the past several decades, the countries that have collaborated with North Korean researchers have changed, suggesting that North Korea may be attempting to maximize collaborations with those countries most willing to interact with it (and be less concerned about the strategic implications of those collaborations), and those countries that have technological expertise that North Korea wants. In practice, this has meant that during the Cold War North Korea relied on Communist bloc countries for knowledge transfer. After the Cold War, North Korea eventually developed a research network that had interactions with a large number of countries, even after sanctions began. This new research network was most intensely focused on collaboration with China, thus mitigating the effects of sanctions.

7.1. 1974-1994: From the Start of the Nuclear Program to the Agreed Framework

In the first period, North Korea's overall research program was relatively small, and its international collaborations were concentrated in only a few countries. This can be seen in Figure 1, in which the nodes represent countries in which authors were located when publishing, and the links represent co-authoring relationships between authors in different countries, with the width of the line indicating the relative number of co-authoring relationships. During this period, while North Korea was not under sanctions, it was firmly in the Communist bloc, and most of its international collaborations necessarily involved doing joint research with other Communist countries. North Korea had particularly dense (and equal) ties with China, Bulgaria, and (East) Germany, although not, interestingly, with the Soviet Union (or later Russia), perhaps reflecting the USSR's (and later Russia's) disinclination to aid North Korea's

42 Ibid.

scientific research after its suspicions about the nature of the DPRK's nuclear program (Figure 1).[43] The USSR had possibly predicated its nuclear assistance to North Korea in the 1980s on North Korea joining the NPT in 1985.[44] In general, North Korea followed the path of least resistance in choosing countries for international collaboration – it collaborated with those countries that were willing, for political reasons, to share knowledge with it.

Figure 1. Country networks (1974-1994)

In terms of the networks as defined by topic area, the fields covered in North Korea's international collaborative research in the initial period were somewhat varied, but the density of the networks was relatively sparse. This can be seen in Figure 2, in which the blue nodes represent research categories, while the grey nodes represent individuals, and the black nodes represent countries. The links between individuals and categories indicate when an individual produces a paper in the category, while the links between individuals and countries indicate the individuals are located in that country when publishing, and the links between categories and countries indicate papers in those categories published by authors in those countries. Physics, chemistry, and to a lesser extent mathematics were the main fields where North Koreans collaborated with foreign researchers. A small number of researchers collaborated a large number of times, which would be indicative of a high potential for tacit knowledge transfer, at least in the specific fields of collaboration. In addition, many of the researchers who served as the main connectors between countries and North Korea were in fact *foreign* researchers, not

43 The graphic uses present-day naming for countries, which may have been part of the USSR during the time period in question.

44 François Carrel-Billiard and Christine Wing, *Nuclear Energy, Nonproliferation, and Disarmament: Briefing Notes for the 2010 NPT Review Conference* (New York: International Peace Institute (IPI), 2010), p. 29.

North Koreans, meaning that North Korea was dependent on a small number of researchers overseas for its knowledge transfer.

Taken together, this would also suggest that North Korea's research collaboration network was not particularly robust since the research collaboration would be based on specific individuals (the absence of whom would impede continued contact in that field between North Korea and the rest of the world). Nor were the different fields studied particularly well integrated – there were few connections between engineering and physics, for example. This suggests that North Korea was not at this point able to link teams doing research on related topics, which is similar to the weaknesses in the integration of its domestic research networks in this period.[45]

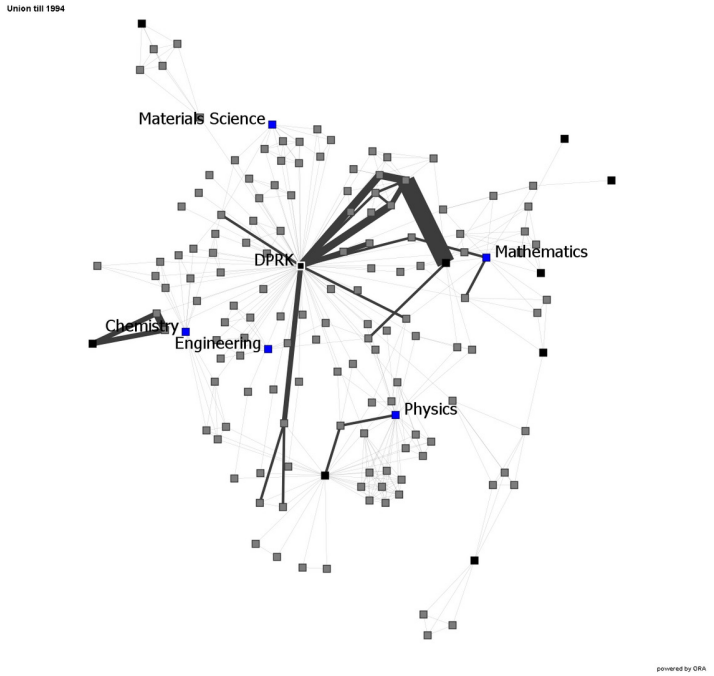

Figure 2. Individual, country, keyword networks (1974-1994)

North Korea's institutional landscape during the decades leading up to the Agreed Framework was also fractured, and researchers were either disconnected from other nuclear-relevant researchers, or were connected largely through affiliations in the same research institutions. Indeed, the two largest clusters of research in this period were both held together not by individual researchers but by institutions. In this period, these institutions included Kim Il Sung University, the Institute for Experimental Biology (of the DPRK), and the Academy of Sciences of North Korea. This can be seen in Figure 3, in which the green nodes represent organisations, and the grey nodes represent individuals. Organisations have a link to individual nodes when the individual is affiliated with that organisation when publishing a paper, while individuals are linked to each other when co-authoring on a paper. This could have hampered North Korea's ability to transfer tacit knowledge within the clusters, given that interactions may have been mediated by the organization. Previous work has found that countries with "siloed" research

45 Philip Baxter, Justin V. Hastings, Philseo Kim, and Man-sung Yim, "Mapping the Development of North Korea's Domestic Nuclear Research Networks," *Review of Policy Research*, Vol. 39, Issue 2 (2021).

institutions, in which researchers are linked through their institutional affiliations, rather than directly linked across institutions, appear to have problems transferring tacit knowledge within the country. The institutions themselves may serve as barriers for researchers within the same country to communicate.[46]

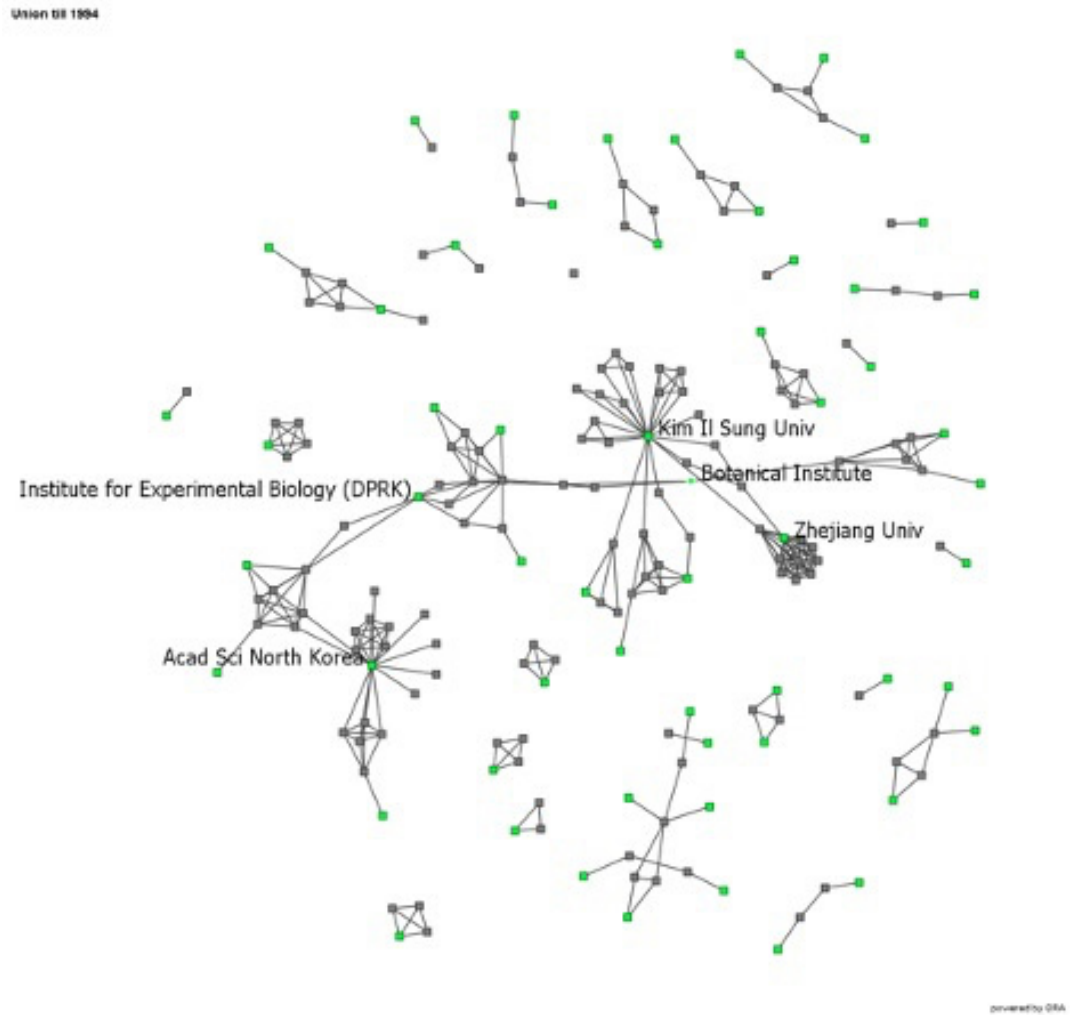

Figure 3. Individual, organization networks (1974-1994)

7.2. 1995-2006: From the Agreed Framework to the First Nuclear Test

Despite its reputation as an internationally isolated country, North Korea has survived in part because it has proven so adaptable to changing international conditions. This also applies to North Korea's efforts to bring in intangible technology. With the collapse of the Communist bloc, North Korea's international collaboration network changed significantly during the

46 Philip Baxter, Adam Stulberg, and Justin V. Hastings, *Examining Subject Matter Networks of Tacit Knowledge Development: The Pakistan Nuclear Program Case Study*, (Atlanta: Georgia Institute of Technology, 2016); Justin V. Hastings, Adam N. Stulberg, and Philip Baxter, *Technology, Materials, and Knowledge Transfer in Nuclear Proliferation Networks: Findings and Implications* (Sydney: University of Sydney, 2015).

Agreed Framework period. Ties with China came to dominate collaboration networks, but new ties to Western countries (particularly in the Nuclear Suppliers Group), as well as India, Israel, and Vietnam (Figure 4) also appeared.

This suggests that North Korea was attempting to diversify its collaboration network as well as draw from countries outside the old Communist Bloc (in fact, the only countries in the Communist bloc that were among the primary collaborators with North Korea after 1994 were China and Vietnam), suggesting a search for more advanced intangible technology. Notably, North Korea was not under any United Nations sanctions before 2006, so the international political environment was as open for North Korean research collaboration, including potentially sensitive research, as it was going to get.

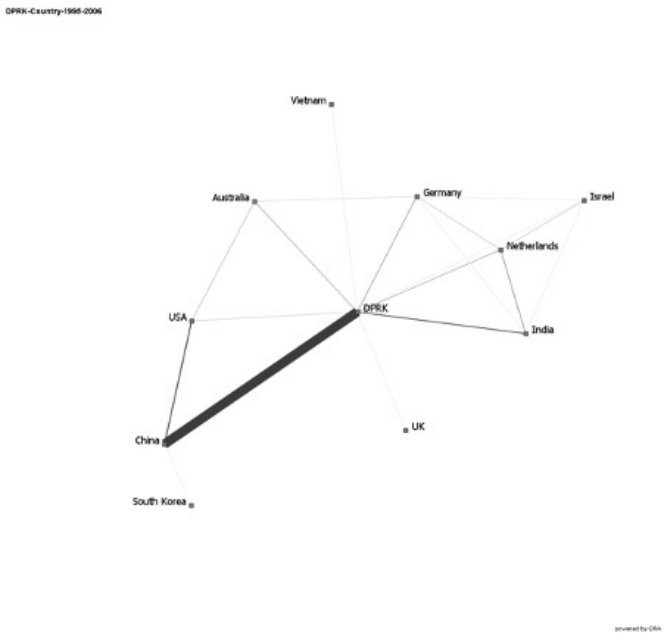

Figure 4. Country networks (1995-2006)

The topics in which North Korean researchers collaborated with international researchers also changed substantially (Figure 5). Materials science, chemistry, and (particularly) physics and engineering emerged not only as areas of significantly increased interest from North Korean researchers, but also served as focal points for developing international collaborations that could facilitate intangible technology transfer. By comparison, computer science and mathematics were relatively neglected. Combined with the concentration of international links shown in Figure 4, Figure 5 indicates North Korean researchers were developing intense, repeated research collaborations with Chinese researchers, particularly in physics and materials science, in the lead up to North Korea's first nuclear test.

An increase in overall publications and authors does not inevitably lead to greater density of collaboration in research networks – indeed, at least for domestic research networks, North Korean collaboration networks were denser than randomized sample networks of similar

size, suggesting that the research communities being built was denser than pure chance.[47] The emergence of North Korean researchers who serve as brokers – the primary links between North Korea and international research collaborators (and countries) – also suggests that North Korea was building a group of researchers who could access and then pass on knowledge to the larger North Korean research community.

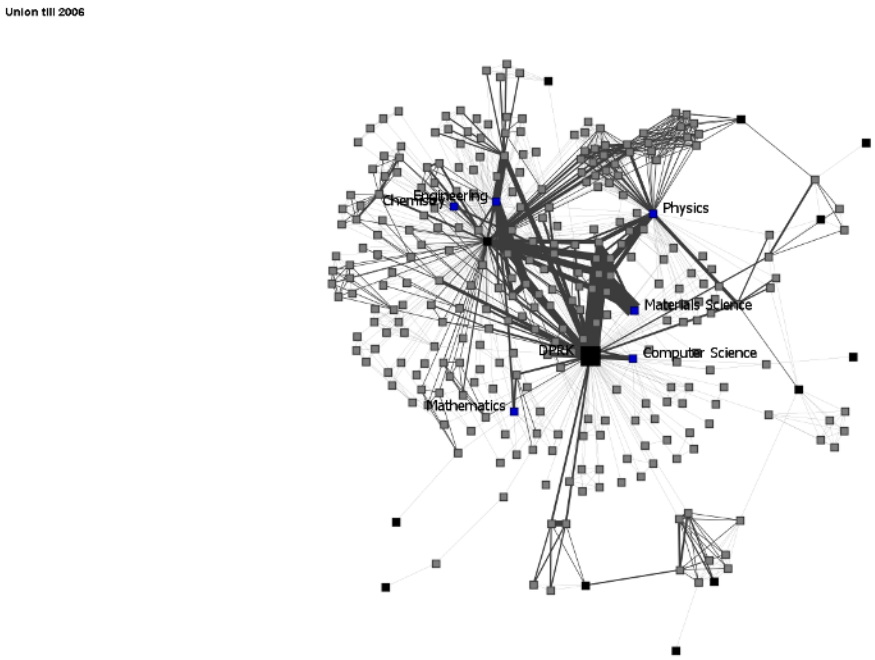

Figure 5. Individual, country, keyword networks (1995-2006)

The period before the first nuclear test also witnessed a consolidation of North Korea's international research network in terms of organizations engaged in nuclear-related scientific research (Figure 6). In addition to Kim Il Sung University and the Academy of Sciences of North Korea, Kim Chaek University of Science and Technology in North Korea also came to prominence, as did a number of Chinese institutions, notably Tianjin University, Tsinghua University, and the China Institute of Atomic Energy. Institutions remained a primary means of connecting disparate research teams, meaning that there were not high levels of interconnectedness among researchers themselves. At the same time, relative to the previous period, direct connections among researchers were increasing. Together, these networks formed a large cluster within North Korea's scientific research community which could be thought of as the beginning of a knowledge community capable of transferring knowledge into and within North Korea. More generally, combined with the North Korean brokers' connections to the outside world, it suggests that North Korean researchers were becoming embedded within a larger international research community during this period.

47 Philip Baxter, Justin V. Hastings, Philseo Kim, and Man-sung Yim, "Mapping the Development of North Korea's Domestic Nuclear Research Networks," *Review of Policy Research*, Vol. 39, Issue 2 (2021), pp. 219-46.

Figure 6. Individual, organization networks (1995-2006)

7.3. 2007-2018: From the First Nuclear Test to the Beginning of North Korea's Diplomatic Pivot

From 2007 to 2018, during a time when North Korea was actively testing (and presumably improving) its nuclear weapons and missile technology and sanctions increased in response, North Korea's research network expanded significantly in terms of the countries of the collaborators (Figure 7). During this period, the vast majority of North Korea's research ties were Chinese collaborators, and to a much lesser extent German collaborators, perhaps reflecting a holdover from North Korea's Cold War ties. North Korean researchers developed relations with collaborators in traditional Nuclear Suppliers Group countries such as France, the Netherlands, Belgium, Switzerland, and Australia (among others) and developing countries with improving technological capabilities, such as Malaysia and Indonesia, and maintained relationships with former Communist bloc countries such as Belarus, Vietnam, and Russia.

The extensive– many countries had at least one research connection with North Korea – but also concentrated – the bulk of connections were with China – nature of the network suggests a strong dependence on China for technology transfer, but also a certain amount of opportunism by North Korean researchers in search of collaborative ties. Given that this period is also when sanctions began to interfere with international collaborations, the extensive network may show the dwindling non-Chinese collaborations as North Korea became dependent on China in a more hostile environment.

Figure 7. Country networks (2007-2018)

In the 2007-2018 time period, North Korea deepened its international collaboration networks in all areas, particularly physics, chemistry, engineering, and materials science (Figure 8). Most of these links were to China. Just as importantly, the topics themselves showed increasing integration, as researchers involved in different but related fields begin to overlap in collaboration networks.

The topics most directly connected to nuclear research – "nuclear" (which includes relevant nuclear engineering, nuclear physics, and plasma physics research), radiation, and isotopic separation – and thus most likely to be subject to sanctions-related restrictions on the transfer of intangible technology (or, more directly, research collaboration and technical assistance), were also the most isolated from the rest of North Korea's research clusters, although they were significantly more extensive in their international links than during the previous period.

This leads to several conclusions. First, North Korea was increasing its international research links in potentially sensitive topics a few years before, or even at the same time as sanctions (including on intangible technology transfer) were increasing. Second, while the extensive deepening of ties in general science areas – physics, chemistry, engineering, and material

sciences – would not necessarily lead to technology transfer directly related to nuclear weapons development, they generally increased North Korea's ability to access intangible technology through intensified research ties in related fields. Third, many of the general scientific topics did indeed contain specific research collaborations that had dual-use implications, particularly in physics, chemistry, and materials science, as documented by the Center for Nonproliferation Studies (CNS).[48] North Korea's burst in lithium processing research in North Korean domestic journals, for example, occurred in the years leading up to its return to nuclear testing in 2016.[49]

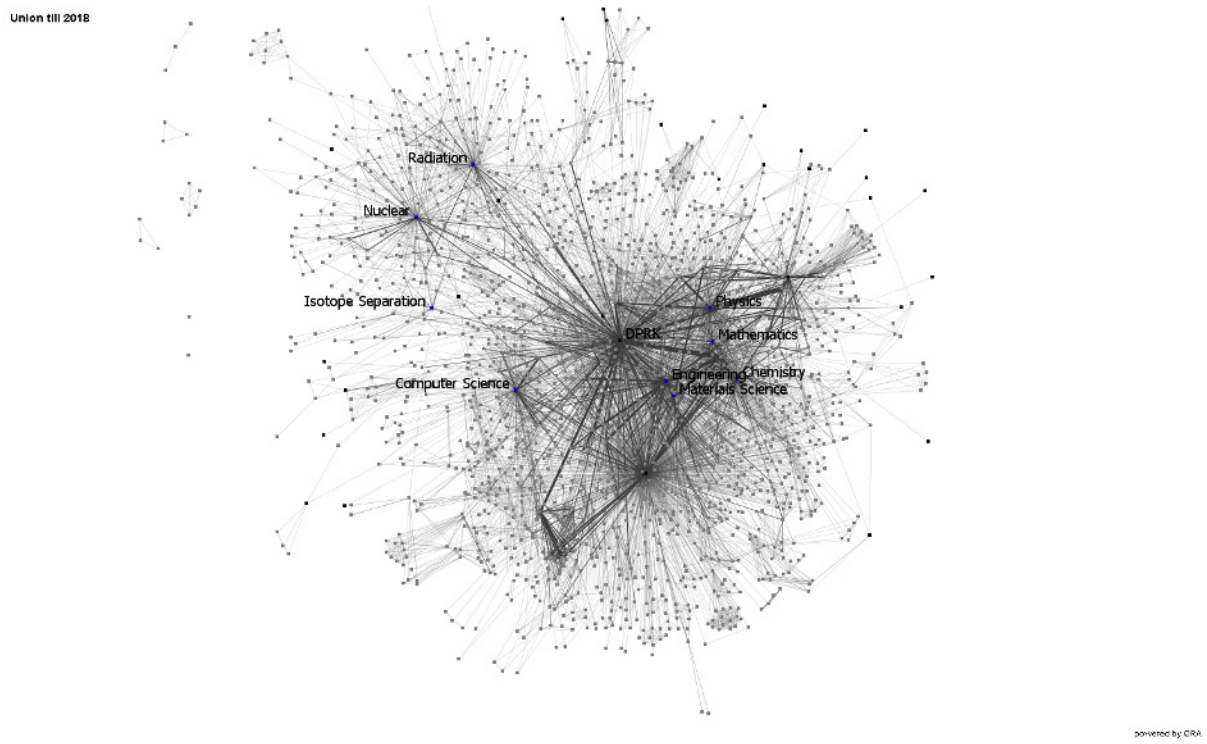

Figure 8. Individual, country, keyword networks (2007-2018)

In the period where North Korea was improving its nuclear weapons and also facing increasing United Nations and unilateral restrictions on tangible and intangible technology transfers, its international collaboration networks actually increased in density relative to previous periods (Figure 9). As part of North Korea's science and technology policy, from around 2011, Kim Jong-un appears to have had a policy encouraging North Korean researchers to publish in international journals, and implicitly to collaborate with foreign researchers, which may explain

48 Joshua H. Pollack and Scott LaFoy, *North Korea's International Scientific Collaborations: Their Scope, Scale, and Potential Dual-Use and Military Significance*, Center for Nonproliferation Studies (Washington, DC, 2018).

49 Justin V. Hastings, Haneol Lee, and Robert Kelley, "North Korea's Lithium Research Networks and its Quest for a Hydrogen Bomb," *Korean Journal of Defense Analysis*, Vol. 30, No. 3 (2018), pp. 337-52.

the increase in collaboration density.[50]

By 2018, North Korea's international collaboration networks were highly interconnected; there were only a few small research clusters within North Korea that were not connected to the large cluster. While institutions continued to provide the linkages among some clusters, by and large, North Korean researchers were embedded within larger research networks that were connected through co-authorships rather than institutions. It was during this period that North Korea's domestic knowledge networks also gradually overcame their silos and established a larger community of interlinked research teams.[51] Kim Chaek University of Science and Technology, and Kim Il Sung University remained prominent, but local Chinese universities (rather than the top central-level ones) such as Northeastern University and Jilin University also emerged as prominent collaborating institutions. This suggests that North Korea had, in this time period, evolved a research community that may be capable of integrating knowledge coming from a variety of sources.

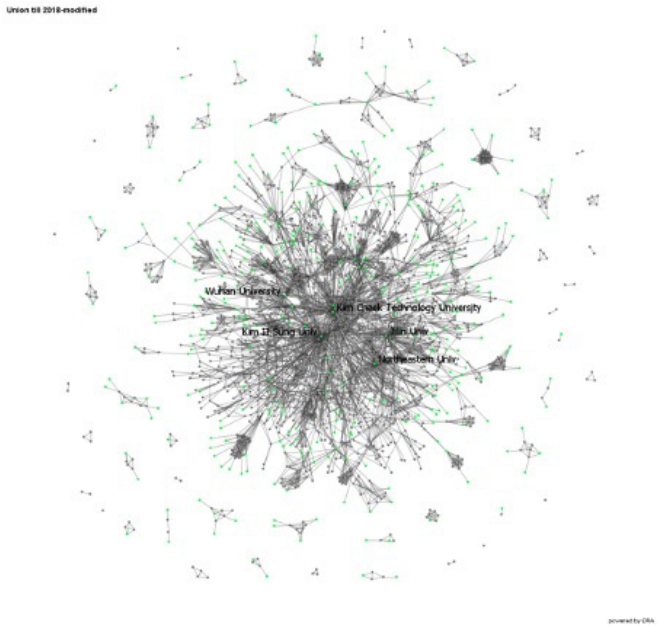

Figure 9. Individual, organization networks (2007-2018)

50 Philip Baxter, Justin V. Hastings, Philseo Kim, and Man-sung Yim, "Mapping the Development of North Korea's Domestic Nuclear Research Networks," *Review of Policy Research*, Vol. 39, Issue 2 (2021); Joshua H. Pollack and Scott LaFoy, *North Korea's International Scientific Collaborations: Their Scope, Scale, and Potential Dual-Use and Military Significance*, Center for Nonproliferation Studies (Washington, DC, 2018).; Kyung-Ran Noh, Eun-Jeong Kim, and Hyun-Kyoo Choi, "A Study on the Production of Science and Technology Knowledge in North Korea through International Academic Papers," *Journal of the Korean Biblia Society for Library and Information Science* 27, No. 4 (2016); Eungi Kim and Eun Sil Kim, "A Critical Examination of International Research Conducted by North Korean Authors: Increasing Trends of Collaborative Research between China and North Korea," *Scientometrics, No.* 124 (2020).

51 Philip Baxter, Justin V. Hastings, Philseo Kim, and Man-sung Yim, "Mapping the Development of North Korea's Domestic Nuclear Research Networks," *Review of Policy Research*, Vol. 39, Issue 2 (2021).

7.4. Individual researchers and international connections

While the networks in different time frames provide snapshots that show how North Korea's knowledge networks have changed over time, tracking individual researcher careers can help to understand North Korea's ability to assimilate tacit knowledge across time periods. While tacit knowledge is transferred through repeated interactions, the knowledge itself resides in individual researchers. As such, individual researchers with long careers are essentially the repositories into which, and from which, tacit knowledge flows (through their connections). It is useful to look briefly at individual researchers inside of North Korea who may serve as the primary repositories of North Korea tacit knowledge about nuclear-related topics.

Like most countries, North Korea has researchers who only publish in domestic journals, researchers who publish only in international journals, and researchers who are capable of publishing in both. Knowledge from foreign collaborators can be transferred into North Korea through collaborations with North Koreans who *only* publish in international journals (which would largely be North Koreans who began their research careers under Kim Jong-un), or by North Korean researchers who write on nuclear-relevant topics in both North Korean domestic journals and international journals.[52] The push under Kim Jong-un to publish in international scientific journals meant that at times there were also North Korean-only teams of researchers publishing in international journals. This would not tell us anything about how international collaborations might lead to intangible technology transfer, although it would tell us about the ability of North Korean researchers, on their own, to develop international-level nuclear-relevant research, and how long it took them.

To look at North Korean researchers who could serve as conduits and repositories of nuclear-related tacit knowledge, we combined a dataset of approximately 1,400 North Korean nuclear-related scientific publications in domestic journals with the international collaboration dataset to find researchers who crossed between domestic publications and international publications.[53]

Of the sixty-one North Korean researchers who started off publishing in domestic journals on nuclear-relevant topics before moving to international journals, 17 later published in international journals in collaboration with foreign researchers. In all cases, the collaborators were at Chinese universities or research centers. In most cases, North Korean researchers who started off in domestic journals and made the jump to international journals did so after a number of years publishing in domestic journals. In one case, the first international publication came 33 years after the first domestic publication (Park Song-yon). However, the researchers involved in research that was more clearly dual-use moved from domestic to international collaboration and international journals more quickly; in the case of Kim Nam-chol, the lag was only 5 years.

There is evidence that North Korea was building a core group of researchers with longstanding

52 Since foreign researchers do not publish in North Korean domestic journals, presumably North Korean researchers who only publish in domestic journals do not have direct exposure to international researchers.

53 Philip Baxter, Justin V. Hastings, Philseo Kim, and Man-sung Yim, "Mapping the Development of North Korea's Domestic Nuclear Research Networks," *Review of Policy Research*, Vol. 39, Issue 2 (2021).

experience and knowledge across rulers: these researchers were not put in place by Kim Jong-un – the majority began publishing under Kim Jong-il and continued publishing well into Kim Jong-un's rule. A short examination of these long-term North Korean researchers suggests that there is a small core group of researchers centered around the Department of Energy Science at Kim Il-sung University (Table 1), who are the main links between internal North Korean research groups and international research teams. The prominence of the Department of Energy Science in the transition between domestic and international level research suggests that it is the main (public) institutional node for tacit knowledge integration in North Korea.

In addition, the researchers who shifted from domestic journals to international journals in collaboration with foreign researchers had a lower median time between domestic and international journal publications compared to those who shifted to publishing in international journals without collaboration, suggesting that the core cadre actually consisted of two groups within the same institutions: one older group that began and continued in isolation, but accrued enough expertise to make the jump to international publications, and another younger group that built connections with Chinese research groups. While some of the Chinese collaborators were likely ethnic Korean Chinese and thus spoke Korean, it is not unlikely that at least some of the North Korean researchers spoke Chinese or English. As such, North Korea has historically relied on an isolated cadre for its institutional knowledge, but it has, under Kim Jong-un, begun building a new cadre that can bring in foreign know-how through international connections.

Table 1. Major North Korean researchers who have published nuclear-related articles in both domestic and international journals

Author	Categories of Research	First international journal appearance	First domestic journal appearance	Time lag (years)	Position	Other Countries Involved
An, Jongdo	Nuclear Physics, Radiation	2015	1995	20	Department of Energy Science, Kim Il Sung University	DPRK only
Choe, Yunsik	Plasma Physics, Radiation, Physics and Astronomy	2015	2007	8	Department of Physics, University of Science	China
Ho, Ilmun	Nuclear Engineering	2020	1995	25	Department of Energy Science, Kim Il Sung University	DPRK only
Jang, Cholho	Materials Science, Radiation	2015	2007	8	Department of Materials Science, Kim Il Sung University	China

Jin, Hakson	Nuclear Physics, Plasma Physics, Radiation, Materials Science, Physics and Astronomy	2012	2000	12	Department of Energy Science, Kim Il Sung University	China
Kim, Cholsu	Physics and Astronomy, Plasma Physics	2015	1997	18	Department of Physics, Kim Il Sung University	DPRK only
Kim, Namchol	Dual-Use, Radiation, Physics and Astronomy	2010	2007	3	Department of Physics, Kim Il Sung University	China
Kim, Songhyok	Dual-Use, Materials Science, Physics and Astronomy	2015	2010	5	Department of Theoretical Physics, Institute of Physics, State Academy of Sciences	China
Pak, Songchol	Plasma Physics	2019	2016	3	Department of Physical Science, Kim Chaek University of Technology	DPRK only
Park, Songyon	Chemical Engineering, Chemistry, Radiation	2019	1986	33	Department of Energy Science (Radiochemistry), Kim Il Sung University	DPRK only
Park, Sungnam	Dual-Use, Materials Science, Radiation	2017	2007	10	Department of Energy Science, Kim Il Sung University	China
Ri, Sunggil	Plasma Physics	2016	1996	20	Department of Energy Science, Kim Il Sung University	DPRK only
So, Chol	Nuclear Engineering, Materials Science	2017	2007	10	Department of Energy Science, Kim Il Sung University	China
U, Yongnam	Nuclear Physics, Radiation, Physics and Astronomy	2005	1992	13	Atomic Energy (Maybe Department of Energy Science), Kim Il Sung University	China

8. Conclusion and Implications

Without inside knowledge of what the North Korean state intended, or what North Korean researchers were thinking, it is difficult to state what North Korea's research community wanted to see happen in knowledge transfer from the 1970s onward. However, what we can observe from the networks created by their research collaborations is that (published) cooperation, and therefore scientific interaction, increased in density. While North Korea began with siloed research communities, different sub-networks gradually came together across institutions and topic areas within North Korea and elsewhere, particularly in the period after North Korea tested its first nuclear weapon. This suggests that tacit knowledge flow increased in North Korea over time.

Strategic trade controls on intangible technology transfer have always been complex. While the provision of explicit knowledge through technical assistance can be regulated, it is more difficult to enforce controls on, for example, emails of blueprints. However, in general, tacit knowledge is *more* difficult to transfer than explicit knowledge. Many of the activities involving close personal interaction in the same physical location – training sessions and workshops, scientific exchanges, employment of researchers abroad working on proliferation-sensitive topics – that would transfer knowledge to North Korea are banned by sanctions or could be curtailed with travel bans.

Research collaboration is more difficult to regulate, particularly inasmuch as researchers, through interaction with other researchers and exposure to research papers, can collect seemingly innocuous pieces of knowledge and put them together to use in strategic contexts.[54] While it may seem straightforward to ban collaboration with researchers in sanctioned countries – in this case North Korea -- as a means of preventing knowledge transfer, this paper suggests that North Korean research collaboration networks have followed a similar adaptive pathway as North Korean trade networks: geographically shifting toward countries that may offer the technologies in which North Korea is interested and/or that offer less regulatory hostility to collaboration between North Koreans and their researchers over time, obfuscating (where possible) the nature of North Korean involvement in the research, and embedding the research most directly relevant to strategic topics in networks of research collaboration in more innocuous fields. All of these strategies take place in a context in which North Korea has, over the long term, cultivated a scientific research community that has increased integration within and outside of North Korea as a way of increasing its ability to take in new knowledge.

This has implications for how to think about strategic trade controls that target intangible technology transfer. First, a focus on specific pieces of knowledge may be too narrow. The extent to which a given single collaboration or interaction could be used to further a country's weapons program should be understood not only in terms of the technical content of the research material produced by the collaboration, but the relationships built up between the collaborators over time, *how* the collaborators interact, and how that interaction is embedded in a larger network of institutional and research collaboration ties.

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54 Wyn Q Bowen and Christopher Hobbs, "Sensitive Nuclear Information: Challenges and Options for Control," *Strategic Analysis*, Vol. 38, No. 2 (2014), pp. 217-29.

Second, and relatedly, tacit knowledge transfer can be successful only if the country seeking it is able to absorb it. As a result, in thinking about strategic trade controls over intangible technology, strategic trade regulators may want to consider the capacity of the recipient country. This could be done through an assessment of the state of scientific research (as represented by research networks) in the country. This assessment would serve two purposes: first, it could assure that technology transferred could be absorbed by the recipient country's research networks, and second, it could allow strategic trade regulators to assess the risk of proliferation-sensitive intangible technology being transferred to countries of concern. North Korea's success in building weapons is a combination of not only integrating foreign knowledge, but also building a domestic research and development infrastructure that was focused on weapons acquisitions and that combined basic research with development and production.[55] At the same time, the cohort within North Korea that is developing foreign collaborative networks and can transfer that knowledge within North Korea is surprisingly small.

Third, because strategic trade controls are theoretically not only supposed to stop the illicit transfer of sensitive materials and knowledge to particular end-users or for certain end-uses, but also *allow* (and even encourage) the transfer of non-sensitive materials and knowledge, looking at how North Korea (or another country) has structured its international collaboration networks can give us an idea about how to engage in technology transfer with states in ways that might encourage peaceful use of nuclear and other technologies.

55 Stephan Haggard and Tai Ming Cheung, "North Korea's Nuclear and Missile Programs: Foreign Absorption and Domestic Innovation," *Journal of Strategic Studies*, Vol. 44, No. 6 (2021), pp. 802-829.