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Roadmapping for the Export of Space Segment Based on Portfolio Analysis: A Case of Korea

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Abstract The space industry is a comprehensive and technology-intensive industry involving different converging technologies. However, most of the companies in Korea's space industry are small and medium-sized enterprises (SMEs) and need to strengthen global capacity to export their products. However, the link between the destination country and the product remains insufficient. Consequently, the purpose of this study is to propose an export roadmap for space products to provide SMEs with export opportunities and strategic guidelines. For this, technology roadmap and portfolio analysis are applied to this purpose. This study is expected to be helpful to SMEs and government agencies.

Keywords Export roadmap, Space industry, Portfolio analysis, Open innovation

I. Introduction

The space industry is a comprehensive technology-intensive industry. Governments around the world are actively investing in the space industry due to its high industrial relevance in employment or technology. In the Republic of Korea (hereinafter: Korea), the space industry is also rated as an energy industry for the realization of the creative economy and the focus on the successful acquisition of technical skills. The global size of the aerospace industry was around $ 340 billion in 2019, and the Korean government is considering the power of the aerospace industry to implement the national economy, trying to acquire the technological skills.

Most companies in the Korean space industry are, however, small and medium-sized enterprises (SMEs) and need to strengthen the global capability to export their space products. Almost all Korean SMEs in the space industry have insufficient technological skills and export records (Park, Lee, Moon, and Kwon, 2016). There are some barriers to exporting Korean SME's space

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products, including policy issues and countrywide security issues. Furthermore, due to a lack of planning capacity, the SMEs have difficulties finding a proper landscape of niches in the technology sectors. As a consequence, government support systems and national-level planning are required to develop the strategies of SMEs' technology innovation and commercialization to enhance the competitiveness of the Korean space industry (Kim, Kim, Suh, and Zheng, 2016). Technology roadmapping (TRM), a tool for considering both internal technological capability and the external market condition, is needed for the purpose of the export of the space product. Nonetheless, the link between the target country and the product remains insufficient.

Accordingly, the purpose of this study is to suggest an export roadmap of space products for offering SMEs with export opportunities and strategic guidelines. The export roadmap is made by considering both the marketability and technology competitiveness of internal space products. The export roadmap is also customized by evaluating each country's market situation, technology level, and policy status. The remainder of this paper is organized as follows: section 2 reviews the preceding research; section 3 presents data and indicators, which includes product marketability and era competitiveness; and section 4 provides the conclusions.

II. Backgrounds

1. Space Industry in Korea

Korea's entry into the space industry took place in the mid-1970s under the leadership of the government. The main players were conglomerates, including Daewoo Heavy Industries, Samsung Space, and Hyundai Space and Aircraft Company. The companies began assembling battalions and helicopters under the license of the US. In 1999, the government merged them and established one company: Korea Aerospace Industries Ltd (KAI). The government also provided 100% for each military project and 50% of the development costs for each commercial aircraft project.

KAI works in conjunction with the Korea Aerospace Research Institute (KARI), a national aerospace research institute, founded in 1989 1989, which began producing rockets and other space technologies for military purposes, but soon entered into aircraft technology, including unmanned vehicles, high altitude aircraft, and is currently involved in the helicopter program. KARI has developed several satellites by cooperating with the University of Surrey, its telecommunications and broadcasting applications. And in 2012, the Korean satellite (KOMPSAT-3) developed by KARI went into orbit. Korea also continues to invest in the development of space technology. Korea succeeded in launching a two-stage Korea Space Launch Vehicle-1 (KSLV-1) rocket from its Naro-Space Center on the southwestern coast of Korea in January 2013. This launch makes Korea the 11th largest country in the world to successfully send a rocket and a satellite into space.

The Ministry of Science, ICT and Future Planning (MSIP) and KARI reported their joint 'Space Development 2020 Roadmap' in November 2013. The revised Korean rocket development plan (2020-2040) and the strategy for industrializing space technology have various mid-to-long-term goals for space development. These include a plan by the Korean government to develop an indigenous rocket capable of launching a 1.5-ton satellite into higher orbit (600-800 km) by 2020. Through immense public investment, international collaboration, and ambitious public and private initiatives, Korea begins building a significant space industry that will mature in the future. Still, private sector spending on R&D accounts for a small fraction of total R&D as most of the private sector firms in this industry are SMEs. Public support for private R&D in this industry comes through many different programs. The export plan in this paper is part of the strategy for the industrialization of space technology with the aim of commercializing space products on the world market and becoming the fourth largest country in the field of space technology by 2040.

2. Technology Roadmapping

Technology roadmapping (TRM) is the method to investigate the advancement of markets, products, and technologies, along with the linkages and discontinuities (Phaal, Farrukh, and Probert, 2004). It is an instrument for strategic technology planning that identifies (1) a certain industry's product performance targets, (2) the technology alternatives and milestones for fulfilling these targets, and (3) a technological path for R&D activities (Garcia, 1997). The first records of the TRM application to support corporate innovation planning date back to the 1980s at Motorola, coordinating different organizational functions such as marketing, finances, manufacturing, and R&D, among others. The fundamental purpose was to align markets, products, and technologies (Kappel, 2001; Rinne, 2004). It provided a framework for connecting business directly to technology and has been broadly used by individual firms, government organizations, and consortia.

There were different types of TRM depending on the purpose, format, and application (Garcia & Bray, 1997; Kappel, 2001; Kostoff & Schaller, 2001; Lee & Park, 2005; Phaal et al., 2004). Phaal et al. (2004) examined a series of roughly 40 roadmaps and grouped them into 16 types: eight types of the roadmap in terms of purpose, such as product planning, capability planning, and strategic planning, and eight types in terms of format, such as multi-layers, bars, and tabular. Kappel (2001) presented the taxonomy of TRM, which was identified according to purpose and focus, e.g., science/technology roadmap, product-technology roadmap, industry roadmap, and product roadmap. Kostoff and Schaller (2001) classified different roadmaps into four types according to their application and goal: S&T maps or roadmaps, industry technology roadmaps, corporate or product-technology roadmaps, and product/portfolio management roadmaps. Hence the roadmapping process and architecture must be adjusted to synchronize with the goal and culture of an organization (Lee & Park, 2005; Phaal et al., 2004).

Beyond the firm-level planning, the TRM has been used as a tool for industry-level planning (Amer & Daim, 2010; Garcia, 1997; Lee, Kang, Park, and Park, 2007) and the national foresight (Saritas & Oner, 2004) by providing specific directions in which industry and society should move forward. These roadmaps are generally issue-oriented roadmaps that identify future national issues such as public-private collaboration, its consequences and provide guidelines for policymakers and decision-makers to fulfill future needs and set directions for the industry's growth. For example, Lee et al. (2009) presented the energy TRM for Korea for the next ten years to provide policy guidance on the country's strategic energy development needs. Similarly, government-oriented TRM for the export of space products to small and medium-sized enterprises in Korea has been required.

TRM has also been adapted in the context of open innovation. Companies are increasingly acquiring technology from outside sources and exploiting or commercializing their technology assets externally. Several studies have noted the importance of strategic technology planning to enable open innovation (Chesbrough & Crowther, 2006). For example, Bagheri et al. (2009) examined open innovation roadmapping, modifying workshop-based traditional roadmapping processes. The guidelines suggested that (1) the source of knowledge should be more open, including well-informed people from outside and quantitative sources; (2) the business model should not be established, and all alternatives should be explored; (3) not only competitors but also start-ups and venture capitals should be considered; (4) the primary function of roadmapping should be to create an option, rather than a research plan; (5) to minimize the false positives and false negatives, the scouting of external technological innovations and preliminary assessment should be investigated, etc.

Furthermore, studies suggested approaches that could include both internal and external sources in TRM. Lichtenthaler (2008) presented an integrated technology commercialization roadmap for a business unit of a large chemical company, which introduced external technology exploitation as a third layer in the existing concept of product-technology roadmaps. Caetano and Amaral

(2011) proposed the roadmapping for technology push and partnership, which consists of identifying and prioritizing the market and partners; potential product concepts; and technologies, technology and financial partners. The final roadmap augments the layers of resources and partners into the traditional roadmap structure: it includes the layers of market, product, core and supplementary technology, resources that are separated into the market, technological and financial, and partners who are collaborators and co-operators. Jeon et al. (2011) implemented TRM with supplier selection portfolios in semiconductor companies in a similar manner. Supplier performance and equipment performance are evaluated using the Analytic Hierarchy Process, and the portfolio maps of suppliers are constructed. Suppliers are then selected on the basis of portfolio trade-offs and are included as the fourth layer of the equipment supplier layer of the roadmap. Geum et al. (2013) proposed dual TRM for outside-in open innovation. The generic structure consists of five layers of market, product, technology, R&D, and partners. It allows for dual layers of internal and external knowledge in the product, technology, and R&D layer, depending on the types of outside-in open innovation: purchasing, in-sourcing, and R&D collaboration. Schwerdtner et al. (2015) have expanded to include regional open innovation, with the aim of making use of the region's innovation potentials for sustainable development and maximizing the prospects for innovation success. As open innovation takes place at the firm, industry, and national level (Jeon, Kim, & Koh, 2015), TRM needs to be integrated into the context of global, international open innovation.

III. Data and Indicators

1. Data

This study develops a strategic roadmap for the export of Korean space products to other countries. It examines, first, the promising segments of Korea's space products and the target countries for entry. Note that the term "product" is used in this study for technologies, components, systems, equipment and service platforms, etc. Promising segments of space products have been selected from previous KARI research. In 2014, space exports in Korea were studied to identify products beyond the prototype stage of technology readiness (Mankins, 2002), which can be competitive and exported within the next five years. The results will be shown in Table 1. The main product segments are five, divided into nine sub-categories, and 21 specific products are included in this study.

Table 1 Promising space product segments of Korea

Product segment		Product
Satellite manufacturing and operation	Satellite manufacturing	- Technical test satellite and on-orbit test analysis tech - Catalyst for single propellant thruster - Valves for single propellant propulsion (thruster valves and charge/discharge valves) - Passive components for satellite mounting - Data transmission system for small and medium satellite payload - Electro-optical payload for small and medium satellites
	Control center and testing facility	- High-resolution and geostationary 3C (Compact, Cheap, Complete) integrated earth station - Integrated control system for geostationary and low-orbit satellite - Satellite control service platform - System for high-speed integrated reception processing of satellite image
Launch vehicle manufacturing and launching	Launch vehicle manufacturing and launching	- System for inertial navigation guidance of launch vehicle - Large-volume liquid hydrogen storage container
	Launchpad and testing facility	-
Satellite service and equipment	Geographic information system	- Global satellite image service platform - Pre-processing technology to improve the quality of satellite image utilization
	Satellite broadcasting and communication	- Low-power micro-modem for the satellite communication terminal - Personal navigation search terminal based on satellite information
	Satellite navigation	- Global Positioning System (GPS) jamming detection and location tracking system
Scientific research		- Spectropolarimeter payload/software (SW) for space weather research
Space exploration		- Biological standard laboratory equipment using International Space Station (ISS) - Qualification Model (QM) for the standard platform of Rover for lunar and planetary explorations - Mid-infrared spectrometer for lunar and planetary explorations

The target countries are selected on the basis of their space import markets and recent political and diplomatic relations with Korea. First, we collected total imports into the UN member countries' space industry from 2008 to 2012. We selected 12 countries with more than one million dollars, including France, Belgium, the US, Kazakhstan, Russia, Japan, Germany, Spain, Italy, Canada, Sweden, and Switzerland in descending import order. The committee of experts approved the selection but suggested that five more countries—India, Turkey, the UAE, China, and Thailand— should be included, taking into account the political and diplomatic opportunities. As a result, 17 countries are selected as the targets for exporting Korean product segments.

The product segments for each of the target countries are analyzed in terms of product marketability, technology competitiveness, and policy trends, which are the key factors of the space export strategy (Goldstein, 2002; Park, Lee, and Lee, 2012), as shown in Figure 1. Product marketability means how much a Korean space product can be marketed in target countries. In order to analyze the product marketability, (1) the intention of the government of each target country to invest a product and (2) the advantage that each target country can gain from importing a product is measured. The data for the research and development (R&D) investment budget from Euroconsult (2014) and import Revealed Comparative Advantage (RCA) index from the UN database are used respectively. Technology competitiveness represents how competitive the Korean space product is in the target countries. It is also measured by (1) a country's technological capability in the product segment and (2) the advantage that each country has by exporting a product using the United States Patent and Trademark Office (USPTO) patent number and export RCA index from UN database. The technology competitiveness can be seen as both a threat and an opportunity: if a target country is competitive in a given product, the country's self-sufficiency threatens exports, but the collaboration with that country can be an opportunity to increase records in the space industry. Policy trends and future plans of the space industry in each country are also identified as milestones for the development of preliminary strategies and timings. The details of measuring product marketability and technology competitiveness are explained below.

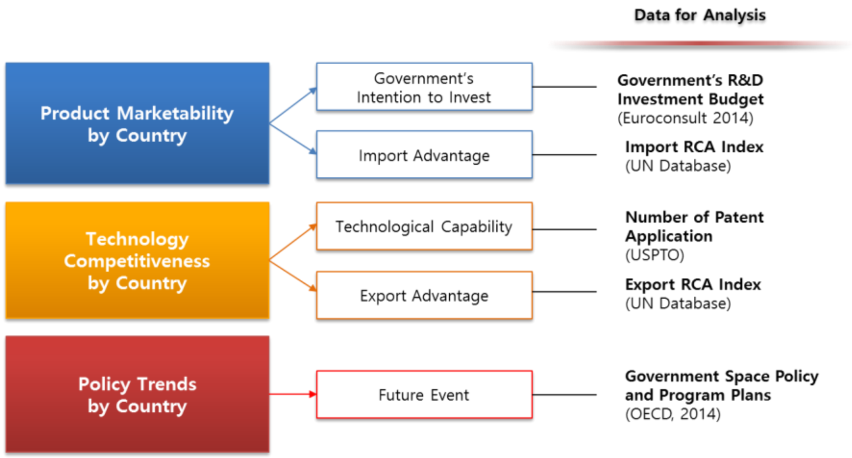


Figure 1 Key Indicators and Data for Portfolio Analysis and Roadmapping

2. Product Marketability

The space industry is developed not only by the interest of the market, but also by the needs of the government. In other words, a product is marketable in a country with demand for a product and government support. Almost since its emergence in the first decade of the 20th century, the space industry has received public support focused on the public benefit of national defense, economic prosperity and impacts on other industries. In this sense, we calculate the government's intention to invest in the research and development (R&D) investment budget. The budget and the cost of R&D were common input factors for technological innovation (Park et al., 2012). In addition, public investment in R&D plays a more critical role in the transfer of technology from external sources to the developed economy (Mowery & Oxley, 1995). Thus, we assume that if a country has raised its government R&D investment budget, it has more *purchasing power* and will be interested in the acquisition or inward transfer of advanced Korean space products.

The data in Table 2 indicate the government's intention to invest scores, the R&D budget of each country in each product segment from 2008 to 2013 normalized (divided) by the total budget of each segment. The entire space R&D investment budget of the target countries is about 245 billion dollars. The US accounts for 55.7% of the candidate countries' overall budget, followed by Russia with 14.3%, China, Japan, France, and Germany in the order. In Table 2, the US achieved the highest scores in almost all product categories, with 0.786 points and 0.650 points in the field of space exploration and science research. Russia has achieved a high score in 'satellite service and equipment' and 'launch vehicle manufacturing and launching.' In France, a relatively high score is obtained in 'launch vehicle manufacturing and launching,' and scores similar to Germany's were obtained. Canada and Spain have an identical score distribution overall. China, Japan, and other countries showed strong performance, but Thailand has zero in 4 fields, the UAE and Turkey have achieved zero in 3 areas.

Table 2 Government's intention to invest (bolds are the top 3 values)

Region	Country	Product segment					Total
		Satellite manufacturing and operation	Launch vehicle manufacturing and launching	Satellite service and equipment	Scientific research	Space exploration	
North America	US	**0.492**	**0.25**	**0.421**	**0.65**	**0.786**	**0.558**
	Canada	0.011	0	0	0.016	0.005	0.008
Europe	Russia	**0.141**	**0.291**	**0.372**	0.048	**0.064**	**0.143**
	France	0.059	**0.159**	0.014	0.039	0.012	0.054
	Germany	0.065	0.028	0.015	**0.053**	0.016	0.041
	Italy	0.027	0.026	0.003	0.041	0.007	0.021
	Spain	0.011	0.005	0.005	0.012	0.001	0.007
	Switzerland	0.004	0.003	0.002	0.005	0.001	0.003
	Sweden	0.004	0.003	0.001	0.007	0	0.003
	Belgium	0.008	0.008	0.002	0.005	0.002	0.006
Asia	China	0.041	0.095	**0.118**	**0.069**	**0.059**	**0.062**
	Japan	**0.089**	0.052	0.033	0.042	0.038	0.060
	India	0.021	0.076	0.012	0.011	0	0.021
	Kazakhstan	0.006	0.003	0.002	0.001	0	0.003
	Thailand	0.002	0	0	0	0	0.001
	UAE	0.011	0	0	0	0.006	0.006
	Turkey	0.008	0	0	0.001	0	0.003
Korea		0.009	0.012	0	0.001	0	0.005

Then, the import advantage is measured by the import RCA (Revealed Comparative Advantage) index. The RCA is an index used in international economics to measure the relative advantage or disadvantage of a particular country in a specific class of goods or services, as evidenced by the flow of trade. It compares the role of a given product in the country's overall exports (imports) compared to the share of that product in world trade. Balassa

(Balassa, 1965) first suggested the RCA measure international trade specialization in different commodities. Although the RCA generally has been computed using export data (export RCA), we use to import data to identify countries that appear to require parts and components from other countries and thus have more *demand* and bigger *market size*. When the RCA indices are determined using import statistics for a component product, the results indicate whether a country has a relative advantage in more upstream assembly operations. (Balassa, 1965; Yeats, 1998). Specifically, the import RCA of country *i* in the product *j* assembly is as follows:

$$RCA_{ij}^{a} = \frac{m_{ij} / M_i}{m_{wj} / M_w} \qquad (1)$$

Where denotes the value of the product *j* imported by country *i* and by the world, and the total imports by country *i* and by the world, respectively. Suppose that the import RCA of a space product j exceeds unity. In that case, the country is said to have a comparative advantage in importing the product: thus likely to be involved and wants to import. On the other hand, if the RCA index is below one, the country is at a comparative disadvantage in importing the product. Thus, assuming that a higher import advantage is higher demand, we understand that a country with a higher RCA index (at least one) has a higher demand for the space products.

Figure 2 underlines the international diversity in import advantages. In Figure 2, the higher import does not necessarily connect to the higher import RCA. France has the highest import but not the best import RCA because the space product import compared to total product import in France is not high. Kazakhstan gets an RCA value of more than 100, which means that the relative ratio of space product imports and the demand for imports is very high. Belgium, France, and the US have high income and RCA index, whereas Turkey, UAE, and Thailand have low import advantage scores. Among 17 target countries, 9 have the advantage, but 8 have a disadvantage in importing space products. Korea has an import amount of about 80 million dollars and an import RCA of 5.089. To remove the effect of scales, we also normalized the import RCA index as the import advantage values from 0 to 1.

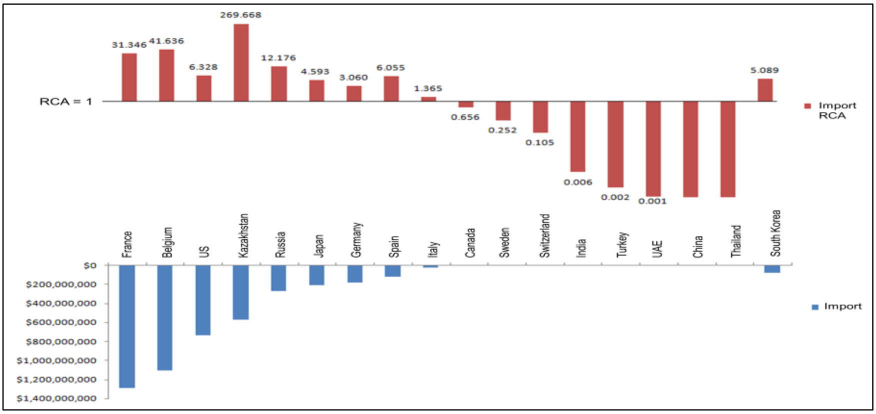


Figure 2 Import RCA (above) and Amount of Import (below)

3. Technological Competitiveness

The technology competitiveness of each country's space product segment is determined by technological capabilities and export competitiveness. Since the space industry is a technology-intensive industry, the national level of technology and export competitiveness of the target countries are critical to the development of the Korean export strategy.

First, the technological capability of each country is calculated by the number of patent applications in product domains. Patent data are a primary source for evaluating the mechanism of innovation and technological change, and patenting rates have long been used as well-founded proxies for assessing technological inventions, new information and literature developments (Acs, Anselin, an Varga, 2002; Burhan, Singh, and Jain, 2016; Fleming & Sorenson, 2001; Park et al., 2012; Trajtenberg, 1990). Several early studies have shown a close association between patent numbers and R&D investment, suggesting that patents are a fair indicator of disparities in innovative competitiveness across various organizations, sectors or nations (Griliches, 1990; Patel & Pavitt, 1997). In the same way, we use the number of patent applications as a technological capability, based on the argument that, if a country applies for a patent in a given product category, it is at or near the technological frontline and has advanced technology competitiveness. (Breschi, Lissoni, and Malerba, 2003; Quintana-García & Benavides-Velasco, 2008).

The patent search formulae in Table 3 are operated in USPTO in Oct. 2015, and the results are described in the last columns of Table 3. The total number of patents cumulated in space products of all countries is 370,752. About 74% of patents are concentrated in the 'satellite manufacturing and operation' field among the five product segments. In all countries except India, the patent numbers of 'satellite control center and testing facility' are the best, and that of 'satellite manufacturing' is the second place. More than 60% of Japanese, Thai, and Turkish space technology patents are concentrated in the 'control center and test facility.' 22.87% of the patent account for 'satellite-related services and equipment.' The patents of 'scientific research' and 'space exploration' are lack in many countries.

Table 3 Formulae and results of patent search

Main category	Subdivision	Patent search formula	Patent number	Patent proportion
Satellite manufacturing and operation	Satellite manufacturing	(SPEC/((satellite and platform) or "satellite bus" or "satellite body") or (payload) or "satellite payload")) and ICN/us	74,957	20.22%
	Control center and testing facility	(SPEC/(satellite) and (control) or (receiving or processing)) and ICN/us	199,307	53.76%
Launch vehicle manufacturing and launching	Launch vehicle manufacturing	(SPEC/("satellite launch") or (launch and vehicle)) and ICN/us	5,631	1.52%
	Launch pad and testing facility	(SPEC/(satellite and launch and pad) or (satellite and launch and ramp) or (satellite and "test bed")) and ICN/us	2,159	0.58%
Satellite service and equipment	Geographic Information System	(SPEC/(satellite and "geographic information system") or (satellite and "geographic information service") or (satellite and GIS)) and ICN/us	2,027	0.55%
	Satellite broadcasting and communication	(SPEC/(satellite and "telecommunication") or (satellite and "broadcast")) and ICN/us	42,010	11.33%
	Satellite navigation	(SPEC/(satellite and (("global positioning system") or	40,758	10.99%

		(“navigation”) or (GPS)))) and ICN/us		
Scientific research	Earth science/ remote exploration	(SPEC/”earth science” or “remote exploration” or “earth observation”) and (ICN/US)	439	0.12%
	Space science	(SPEC/cosmology or “space science”) and (ICN/US)	284	0.08%
	Planetary science	(SPEC/planetology or “planetary science”) and (ICN/US)	113	0.03%
	Astronomy	(SPEC/astronomy or “celestial body”) and (ICN/US)	2,030	0.55%
Space exploration	Unmanned space exploration	(SPEC/(robotic or unmanned) and (“space exploration” or “space probe”)) and (ICN/US)	182	0.05%
	Manned space exploration	(SPEC/(manned or human) and (“space exploration” or “space flight”)) and (ICN/us)	855	0.23%

To measure the relative share of countries’ technological capability in each product segment, we normalized the number of patents for each product in each country by the total number of the product segments. As shown in Table 4, the US occupies 69.2% of the countries’ total patents has the highest scores in almost all product categories. Japan and Canada have achieved second and third place in most fields, and Korea is the fourth country in technological capability. France has a high score in ‘launch vehicle manufacturing and launching’ whereas Germany also has a high score in ‘scientific research’ and ‘space exploration’; those two countries have a similar distribution. China and India, Italy, and Switzerland also have a similar score distribution as well. Korea has strong technological capability in ‘satellite service and equipment’ and ‘satellite manufacturing and operation’. Kazakhstan, Thailand, UAE, and Turkey have achieved zero in technical capability.

Table 4 Technological capability (bolds denote top 3 values)

Region	Country	Product segment					Total
		Satellite manufacturing and operation	Launch vehicle manufacturing and launching	Satellite service and equipment	Scientific research	Space exploration	
North America	US	**0.684**	**0.852**	**0.702**	**0.663**	**0.882**	**0.692**
	Canada	**0.037**	**0.031**	**0.037**	0.041	**0.035**	**0.037**
Europe	Russia	0.004	0.009	0.004	0.005	0.004	0.004
	France	0.023	**0.026**	0.018	0.058	0.010	0.022
	Germany	0.028	0.019	0.032	**0.063**	**0.026**	0.029
	Italy	0.006	0.004	0.005	0.011	0.003	0.006
	Spain	0.002	0.002	0.002	0.005	0.001	0.002
	Switzerland	0.007	0.003	0.006	0.012	0.004	0.006
	Sweden	0.011	0.014	0.010	0.007	0	0.011
	Belgium	0.003	0.001	0.002	0.003	0.002	0.003
Asia	China	0.017	0.006	0.010	0.009	0.007	0.015
	Japan	**0.116**	0.021	**0.117**	**0.101**	0.012	**0.114**
	India	0.027	0.008	0.010	0.005	0.003	0.022
	Kazakhstan	0	0	0	0	0	0
	Thailand	0	0	0	0	0	0
	UAE	0	0	0	0.001	0	0
	Turkey	0	0	0	0.001	0	0
Korea		0.034	0.005	0.045	0.018	0.012	0.036

Like in the import advantage, the export advantage is measured by the export RCA index of country *i* in the product *j* is:

$$RCA_{ij}^{p} = \frac{x_{ij} / X_i}{x_{wj} / X_w} \qquad (2)$$

In the above formula, the *x* represents exports, and all other definitions refer to the terms in equation (1). The index also has a reasonably clear interpretation. If its value exceeds unity, the country is interpreted to have a comparative advantage in the output of the product *j*. On the other hand, if the RCA index is below one, the country has a relative disadvantage in the production of the said products. We understand this as the competitiveness of a country when it exports a product to other countries. As illustrated in Figure 3 of exports from 2008 to 2013, the larger exports, the higher the export advantage index. Italy, France, and Germany have more than ten export RCA indices, and UAE, Russia, and the US also have export RCA index above 1. The five countries, Belgium, Kazakhstan, Japan, India, and Thailand, do not have any export in space segments during the time we investigated. Compared to others, Korea is ranked as the fourth export advantage with 5.504. Like in the import RCA, we normalized the import RCA index as the import advantage values from 0 to 1.

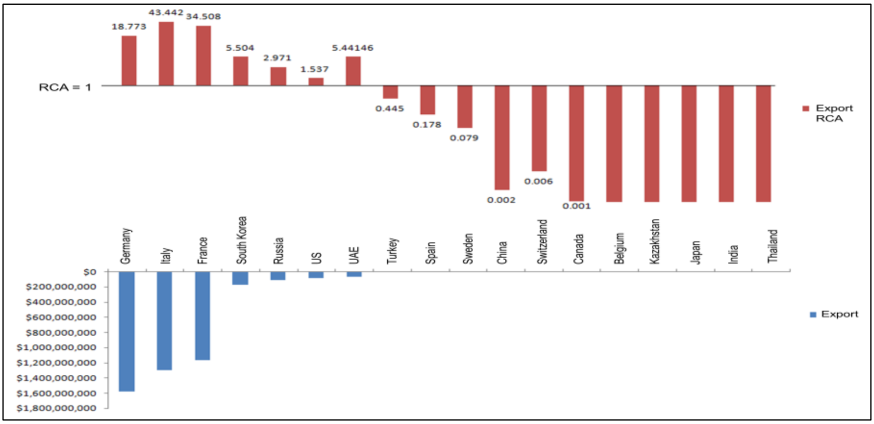


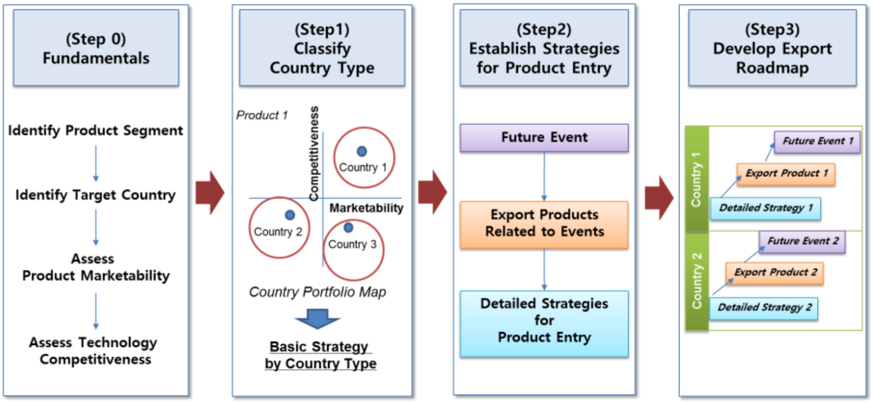
Figure 3 Export RCA and Amount of Export

Aggregating corresponding indices calculate the final scores of product marketability and technology competitiveness. We calculate the average of normalized indexes of governments' intention to invest and import advantage and multiply a hundred to re-scale as one hundred points for product marketability. The same process is also applied to technological capability and export advantage.

IV. Roadmapping for Export of Space Product

1. Overall Procedure

The target countries will have heterogeneous product marketability and technology competitiveness for each product category. There are various circumstances in which different specific techniques for entry can be developed. For example, if a country has strong marketability and technology competitiveness, it is an attractive yet highly competitive market; encouraging exports to that market, engaging in projects led by that country, seeking subcontracting are acceptable strategies. In contrast, if a country has high marketability and low technological capability, it is highly dependent on import because it cannot manufacture the necessary product; in this situation, the export contracts may be enabled by government collaboration or programs subject to transferring superior Korean technologies. Thus, comprehensive roadmapping is implemented in three steps: the definition of the country type using portfolio map, the establishment of product entry strategies, and the development of export roadmap (see Figure 4).



Note: This framework has been proposed by Jeon & Kim (2017)

Figure 4 Process of Export Roadmapping for Space Product segment

First, portfolio maps are established with product marketability and technology competitiveness scores to characterize target countries. Figure 5 and Table 5 illustrate the structure of the portfolio map and corresponding country types. The X-axis of the portfolio map shows the product's marketability, the Y-axis shows the technology competitiveness, and countries are mapped. The product marketability and technology competitiveness can be divided into three levels: good, average, and low. According to the combination of the levels in two axes, the types of countries are determined as eight categories: advanced, technology-driven, import-dependent, medium, technology-backed, market-backed, self-reliant, and undeveloped.

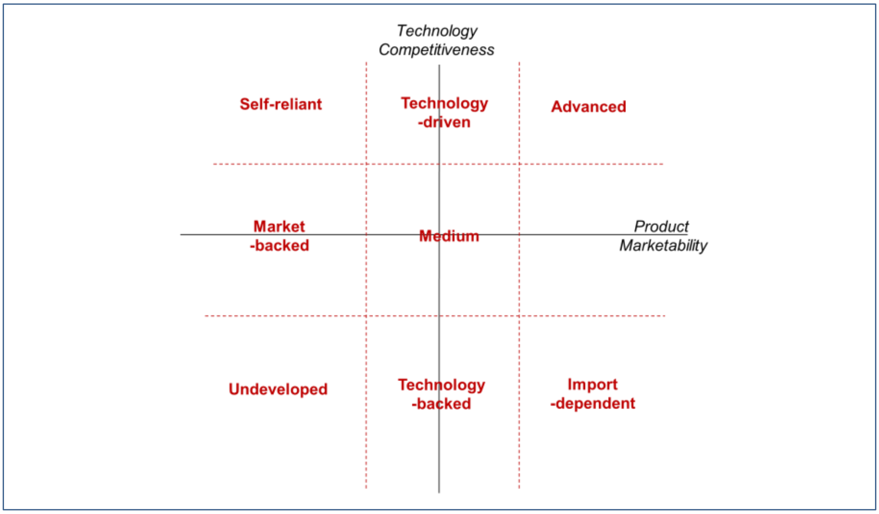


Figure 5 Portfolio Map and Boundaries of Classification

Table 5 Criteria for classification

Country type	Product marketability	Technology competitiveness
Advanced	Good	Good
Technology-driven	Average	Good
Import-dependent	Good	Low
Medium	Average	Average
Market-backed	Low	Average
Technology-backed	Average	Low
Self-reliant	Low	Good
Undeveloped	Low	Low

Second, based on each product and country's product marketability and technology competitiveness, the strategy to link countries and products (i.e., what and how to sell to whom) is derived. According to their product marketability and technology competitiveness levels, we establish the basic entry strategies in Table 6. For example, *advanced* countries are good at both marketability and competitiveness. As we noted above, they are attractive due to marketability but highly competitive due to the competition with internal technologies. Thus, it is plausible to pursue to participate in large projects led by that country or find outsourcing or subcontracting businesses that start entry in expendable components. *Technology-driven* countries have high competitiveness but average marketability. Based on their technology competitiveness, co-innovation projects can be promoted to absorb the advanced technological knowledge from those countries. The discovering of businesses with the joint-investment agreement can also be pursued for filling business references and experiences. *Import-dependent* countries, which have good marketability but low competitiveness, are the priority market for Korean SMEs. Government-level relationships can strategically and relatively quickly achieve export. As they must require space products and technology, the entry strategy can be the business regarding the technology transfer from Korea.

Table 6 Basic entry strategy by target country type

Country type	Basic entry strategy
Advanced	- Entering as a participant in the large size projects of an advanced country - Identifying the outsourcing businesses of expendable products in an advanced country
Technology-driven	- Participating in co-innovation projects for acquiring advanced technologies of a technology-driven country - Discovering businesses with investment agreement for filing business references and experiences
Import-dependent	- Identifying businesses on the premise of technology transfer and training of engineers - Activating export contracts based on a government-level cooperative relationship
Medium	- Constructing government-level technological cooperation - Seeking for technology license and joint advancement into third countries
Market-backed	- Promoting PPP (Public-Private Partnerships) businesses - Considering preliminary investment for the prior occupation of the market
Technology-backed	- Developing business can deliver technological capabilities, such as ODA (Official Development Assistance), technology transfer, and educational programs
Export-oriented	- Lowering the entry barrier through an agreement between governments like the Free Trade Agreement. - Pushing forward a joint business in third countries
Developing	- Raising funds by market vitalization, using PPP (Public-Private Partnerships) businesses - Driving investment of governments and companies on the premise of technology transfer
Undeveloped	- Inspiring government' willingness to support innovation by cooperation - Vitalizing the participation of government and companies based on technology transfer - Developing pre-investment business for raising fund and secure reference

Using basic guidelines, detailed product entry strategies are established using detailed future events according to the future space plans of the countries. Future events, such as the launch or creation of a satellite, can be a focal point for preparing when and what to do for exports. In particular, the product segments corresponding to potential events are thus defined. Described strategies for product entry shall be developed by combining basic strategies, future events, and related product segments.

Finally, the export roadmaps for each product segment are created. Roadmap layers are target countries with divisions and three components of potential activities, export goods, and comprehensive entry techniques that are tailored to their time for intervention and dependency.

2. Classification of Country Type using Country Portfolio Map

We constructed the country portfolio maps for nine sub-divisions of product segments. One example of the satellite manufacturing segment is presented in Figure 6. The intersection (origin) of the two axes is set to the average values: 5.58 of marketability and 5.56 of competitiveness. The thresholds, 1 and 10, are determined based on the scores' distribution: as standard deviations are 9.58 and 9.31, and data are concentrated on small values (note that we applied log scale in Figure 6). The levels of product marketability and technology competitiveness are thus divided into good (10~100), average (1~10), and poor (less than 1), and countries are classified into eight types. In Russia's case, we reflect on the impact of political issues with the US on the USPTO patent registration. Since Russia would not apply all of their technology to USPTO, it is assumed that technology competitiveness is higher than patent data. Consequently, we classified the US and Russia (technology competitiveness adjustment) as advanced; France, Germany, and Italy as technology-driven; Kazakhstan as import-dependent; Japan, India, and China as a medium; Canada and UAE as market-backed; Spain and Belgium as technology-backed; and Sweden, Switzerland, Turkey, and Thailand as undeveloped countries. The classification results for all segments are involved in Table 7.

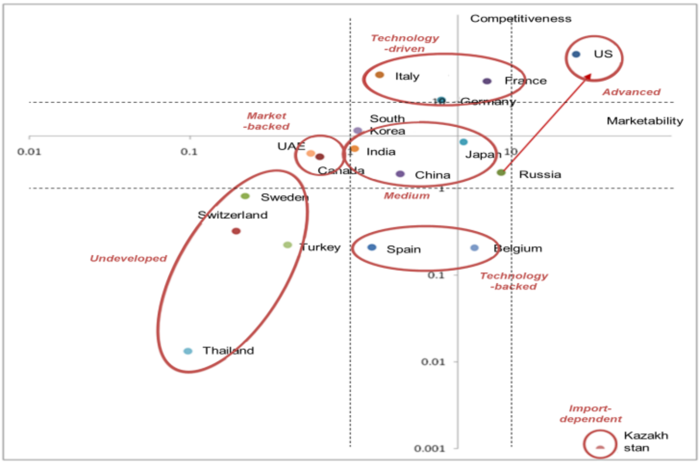


Figure 6 Country Portfolio Map: 'satellite manufacturing' Segment

Table 7 Results of classifying countries: 'satellite manufacturing' segment

		Advanced	Technology-driven	Import-dependent	Medium	Market-backed	Technology-backed	Self-reliant	Undeveloped
Satellite manufacturing and operation	Satellite manufacturing	US Russia	Italy Germany France	Kazakhstan	China Japan India	Canada UAE	Belgium Spain	-	Sweden Switzerland Turkey Thailand
	Control center and testing facility	US Russia	Italy Germany France	Kazakhstan	-	Canada UAE	Spain China India Belgium	-	Sweden Switzerland Turkey Thailand
Launch vehicle manufacturing and launching	Launch vehicle manufacturing and launching	US Russia France	Italy	Kazakhstan	Japan Germany	Canada UAE	Spain China India Belgium	-	Sweden Switzerland Turkey Thailand
	Launch pad and testing facility	US Russia France	Italy	Kazakhstan	Germany	Canada UAE	Spain China Japan India Belgium	-	Sweden Switzerland Turkey Thailand
Satellite service and equipment	Geographic information system	US Russia	France	Kazakhstan	Germany Japan	Canada UAE	Spain China Belgium	Italy	Switzerland Sweden India Turkey Thailand
	Satellite broadcasting and communication	US Russia	Germany France	Kazakhstan	Japan Germany	Canada UAE	Spain China Belgium	Italy	Switzerland Sweden India Turkey Thailand

	Satellite navigation	US Russia	Germany France	Kazakhstan	Japan	Canada UAE	Spain China Belgium	Italy	Switzerland Sweden India Turkey Thailand
Scientific research		US	Italy Germany France Russia	Kazakhstan	Japan	Canada UAE	Spain China Belgium	-	Switzerland Sweden India Turkey Thailand
Space exploration		US	Germany France Russia	Kazakhstan	-	Canada UAE	Spain China Japan Belgium	Italy	Switzerland Sweden India Turkey Thailand

3. Establishment of Product Entry Strategy

We investigated and collected the future events of related space product segments from various sources of each country's policy research reports for specific product entry strategies. The typical conceivable future events can be national space programs, a satellite launch, product and technology development, and schedules of product and system modernization, etc. In our case study, referring to the reports, including Euroconsult (2014) and the OECD (2014), we extracted the plans related to five product segments and organized them in each country by year. The example of the satellite manufacturing segment is presented in Table 8.

Table 8 Future events collected: 'satellite manufacturing' segment

Country	Year	Future event
US	2016	Launching data relay telecommunication satellite *TRDS-M*
	2017	Launching geostationary communication satellite *AEHF4*
	2018	Launching geostationary communication satellite *AEHF5*
	2019	Launching geostationary communication satellite *AEHF6*
	2020	Modernization plan to improve satellite performance
Russia	2019	Developing next-generation satellite (by technology transfer)
	2020	Launching earth observation satellite *KazEOSat4*
		Manufacturing additional optical image satellite
	2022	Launching non-military communications satellite *KazSat-4*
Italy	2017	Launching high-resolution military earth observation satellite *Opsat*
		Launching hyperspectral satellite for environmental monitoring and underground resource detection *Shalom*

	2019	Launching hyperspectral payload on-orbit test satellite *PRISMA*
Germany	2016	Developing small geostationary satellite platform
	2017	Launching earth observation satellite *TerraSAR-X2*
	2018	Launching radar reconnaissance satellite *SARah1*
		Launching technical test satellite *DEOS*
	2019	Launching radar reconnaissance satellite *SARah2,3*
France	2016	Launching science experiment satellite *MICROSCOPE*
		Developing large-scale rapid processing satellite for Ka and Q-V bands
	2017	Launching military earth observation satellite *CSO1*
	2018	Launching military earth observation satellite *CSO2*
		Launching earth observation satellite *Mistigri* (plan)
	2019	Launching observation satellite for greenhouse gas research *MERLIN*
	2020	Launching earth observation satellite *SWOT* and *CERES1,2,3*
	2021	Launching geostationary satellite for ocean research *GeOCAPI*
Kazakhstan	2019	Developing next-generation satellite (by technology transfer)
	2020	Launching earth observation satellite *KazEOSat4*
		Manufacturing additional optical image satellite
	2022	Launching non-military communication satellite *KazSat-4*
Japan	2017	Launching earth observation satellite *ASNARO3*
	2019	Launching optical satellite *ALOS3*
	2020	Lending DSN(Defense System Network) consortium satellites
China	2016	Launching earth observation satellite *ZY-3*
		Launching meteorological satellite *FY-4A*
	2016-2018	Launching reconnaissance satellite *YG Series*
		Launching earth observation satellite *CHEOS Series*
	2016-2019	Launching disaster monitoring satellite *HJ Series*
	2017	Developing satellite platform *DFH-5*
	2017-2020	Launching ocean observation satellite *HY Series*
	2018	Launching meteorological satellite *FY-4B*
	2019-2020	Launching military communication satellite *FH Series*
	2020	Launching meteorological satellite *FY-4C*
India	2016	Launching earth observation satellite *Cartosat-3*, *GISAT1*, and *Resourcesat-2A*,
		Launching geostationary communication satellite *GSAT17*

		Launching meteorological satellite *Insat3DR*
	2017	Launching communication satellite *GSAT-7A*
		Launching geostationary communication satellite GSAT18
	2019	Launching earth observation satellite *NISAR*
	2020	Launching military communication satellite *CCI-Sat*
Belgium	2016	Launching earth atmospheric observation satellite *PICASSO*
		Launching technical test satellite *QARMAN*
Spain	2016	Launching earth observation satellite *Ingenio*
		Launching thermosphere research satellite *QBITO*
	2017	Launching Ku, Ka band communication satellite *Amazonas5*
	2019	Joint participation in developing National Institute for Space Technology (INTA) rocket engine
Canada	2018	Launching earth observation satellite *RADARSAT*
	2020	Broadband communication with communication satellite *PCW*
UAE	2016	Establishing Abu Dhabi spaceport
	2017	Launching earth observation satellite *KhalifaSat*
	2018	Launching communication satellite *AlYah3*
		Launching military earth observation satellite *FalconEye-1*
	2019	Launching military earth observation satellite *FalconEye-2*
	2020	Developing and launching communication satellite *YahSat*
Thailand	2016	Launching communication satellite *Tahicom8*
	2018	Announcement of new space plan
	2019	Launching earth observation satellite THEOS-2
Sweden	2016	Investing in computers, telecommunication equipment in satellites
		Developing small geostationary satellite *SGEO* platform
Switzerland	2016	Launching communication satellite *AOneSat-1*
	2017	Launching the European Space Agency (ESA)'s exoplanet exploration satellite *CHEOPS*
Turkey	2016	Launching communication satellite *Turksat-5A*
		Launching military earth observation satellite *Gokturk-1*
	2019	Launching military earth observation satellite *Gokturk-3*
	2020	Launching communication satellite *Turksat-6A*
		Launching military earth observation satellite *Gokturk-4*

Next, the linkage between future events collected and specific products from the segment are investigated, as shown in Table 9. This process was for identifying more specific details in roadmapping.

Table 9 Linking products with future events: 'satellite manufacturing' segment

Country	Future event	Export products related to events
US	• Plan to satellite performance modernization • Launching satellites - Relay communications satellite - Geostationary communication satellite	• Electro-optical payload for small and medium satellites • Passive components for satellite mounting • Data transmission system for small and medium satellite payload and small
Russia	• Joint development of next-generation satellite • Producing additional optical image satellite • Launching satellites - Earth observation satellite - Non-military communications satellite	• Passive components for satellite mounting • Data transmission system for small and medium satellite payload • Electro-optical payload for small and medium satellites • Valves for a single propellant propulsion system • Catalyst for single propellant thruster • Technical test satellite and on-orbit test analysis technology
Italy	• Launching satellites - High-Resolution military earth observation satellite - Hyperspectral payload on-orbit test satellite - Hyperspectral satellite	• Electro-optical payload for small and medium satellites • Valves for a single propellant propulsion system • Data transmission system for small and medium satellite payload • Catalyst for single propellant thruster
Germany	• Development of small geostationary satellite platform • Launching satellites - Earth observation satellite - Radar reconnaissance satellite - Technical test satellite	• Technical test satellite and on-orbit test analysis technology • Valves for a single propellant propulsion system • Catalyst for single propellant thruster • Data transmission system for small and medium satellite payload
France	• Launching satellites - Science experiment satellite - Military earth observation satellite - Earth observation satellite - Observation satellite for greenhouse gas research - Geostationary satellite for ocean research	• Electro-optical payload for small and medium satellites • Data transmission system for small and medium satellite payload • Passive components for satellite mounting
Kazakhstan	• Joint development of next-generation satellite • Launching satellites - Earth observation satellite - Optical image satellite - Non-military communications satellite	• Passive components for satellite mounting • Data transmission system for small and medium satellite payload • Valves for a single propellant propulsion system • Electro-optical payload for small and medium satellites • Catalyst for single propellant thruster • Technical test satellite and on-orbit test analysis technology

China	• Developing satellite platform • Launching satellites - Earth observation satellite - Reconnaissance satellite - Earth observation satellite - Meteorological satellite - Disaster monitoring satellite - Ocean observation satellite - Military communication satellite	• Passive components for satellite mounting • Data transmission system for small and medium satellite payload • Electro-optical payload for small and medium satellites
Japan	• Lending DSN consortium satellites • Launching satellites - Earth observation satellite - Optical satellite	• Data transmission system for small and medium satellite payload • Electro-optical payload for small and medium satellites • Valves for a single propellant propulsion system • Catalyst for single propellant thruster
India	• Launching satellites - Earth observation satellite - Geostationary communication satellite - Meteorological satellite - Military communication satellite	• Data transmission system for small and medium satellite payload • Electro-optical payload for small and medium satellites • Technical test satellite and on-orbit test analysis technology • Passive components for satellite mounting • Valves for a single propellant propulsion system • Catalyst for single propellant thruster
Canada	• Broadband communication with communication satellite PCW • Launching satellites - Earth observation satellite	• Data transmission system for small and medium satellite payload • Passive components for satellite mounting • Passive components for satellite mounting • Valves for a single propellant propulsion system • Electro-optical payload for small and medium satellites • Catalyst for single propellant thruster
UAE	• Establishing Abu Dhabi spaceport • Launching satellites - Earth observation satellite - Communication satellite - Military earth observation satellite	• Valves for single propellant propulsion system Passive components for satellite mounting • Catalyst for single propellant thruster • Data transmission system for small and medium satellite payload • Electro-optical payload for small and medium satellites
Belgium	• Launching satellites - Earth atmospheric observation satellite - Technical test satellite - Communication satellite	• Technical test satellite and on-orbit test analysis technology • Passive components for satellite mounting • Valves for a single propellant propulsion system • Data transmission system for small and medium satellite payload • Catalyst for single propellant thruster

		• Electro-optical payload for small and medium satellites
Thailand	• Announcing new space plans • Launching satellites - Earth observation satellite - Communication satellite	• Passive components for satellite mounting • Technical test satellite and on-orbit test analysis technology • Data transmission system for small and medium satellite payload • Electro-optical payload for small and medium satellites • Valves for a single propellant propulsion system • Catalyst for single propellant thruster

Last, the detailed entry strategies are established for a set of future events and products by integrating basic strategy, as discussed in Table 6. For example, Kazakhstan was classified as an import-dependent type, with higher marketability and less competitiveness, which means a highly opportunistic market for the export. As noticed in the basic strategy, a cooperative relationship between governments is essential to activate export contracts. The deliverables can be joint development, technology transfer conditions, and education programs for engineers. The results are shown in Table 10.

Table 10 Establishing detailed export strategies: 'satellite manufacturing' segment

Type	Country	Detailed strategies for product entry
Advanced	US	• Cooperative dialogue with the US government on the space industry • Participating in the modernization project to improve the satellite performance of the US Department of Defense by 2020
	Russia	• Consultation on joint development of next-generation satellite and optical satellite at government level • Discussion of product export and technology transfer conditions • Product design and development • Providing education programs for technology transfer and education/training of technicians
Technology-driven	Italy	• Proposing a joint development project for the production of earth observation satellite for developing countries • Conducting negotiations for developing countries • Commencement of joint development project • Discussing business specification and technology transfer conditions
	Germany	• Proposing a joint development project for the production of technical test satellite for developing countries • Conducting negotiations for developing countries • Commencement of joint development project
	France	• Proposing a joint development project for the production of communication satellite for developing countries • Conducting negotiations for developing countries • Commencement of joint development project
Import-dependent	Kazakhstan	• Consultation on joint development of next-generation satellite and optical satellite at government level

		• Discussion of product export and technology transfer conditions • Product design and development • Providing education programs for technology transfer and education/training of technicians
Medium	China	• Establishing establish technological cooperation between governments or between major space agencies • Exchanging technology license and processing joint technical development program • Finding and developing cooperation project for export satellite for developing countries • Launching joint development of satellite after consultation with developing countries
	Japan	• Establishing establish technological cooperation between governments or between major space agencies • Exchanging technology license and processing joint technical development program • Finding and developing cooperation project for export satellite for developing countries • Launching joint development of satellite after consultation with developing countries
	India	• Establishing establish technological cooperation between governments or between major space agencies • Exchanging technology license and processing joint technical development program • Finding and developing cooperation project for export satellite for developing countries • Launching joint development of satellite after consultation with developing countries
Market-backed	Canada	• Recruiting domestic and foreign investment to enter the investment type market • Step-by-step market entry starting from promising satellite products
	UAE	• Processing government-level negotiation for identifying PPP project • Recruiting public/private participants • Promoting full-fledged progress of PPP projects and continuous market development
Technology-backed	Spain	• Inducing government and business to invest in satellite • Finding PPP business based on technology transfer for market activation • Processing PPP project with public/private participants
	Belgium	• Finding projects involving technology transfer and education to the Belgian government • Step-by-step planning for business details and technology transfer • Providing education programs for technology transfer and education/training of technicians
Undeveloped	Sweden	• Inducing government and business to invest in satellite • Finding PPP business based on technology transfer for market activation • Processing PPP project with public/private participants
	Switzerland	• Inducing government and business to invest in satellite • Finding PPP business based on technology transfer for market activation

		• Processing PPP project with public/private participants
	Turkey	• Inducing government and business to invest in satellite • Finding PPP business based on technology transfer for market activation • Processing PPP project with public/private participants
	Thailand	• Establishing friendly relations with the Thai government and encouraging market development • Identifying the demand for satellite products considering the timeliness • Finding PPP business based on technology transfer • Finding investment-type projects based on technology transfer • Recruiting public/private institutions participating in the PPP project • Continuous market development • Providing education programs for technology transfer and education/training of technicians

4. Development of an Export Roadmap

The final export roadmaps are constructed, as shown in examples of Figures 7 and 8. The layers of the roadmap are defined as portfolio types of countries and assigned countries. The roadmap helps to identify plans for a specific group with a similar strategy by showing homogenous groups of portfolios together. Future events are mapped according to their expected and planned times. The linked target products are mapped considering the timeline of future events and times for development. Then, the entry strategies are also related to the relevant target products.

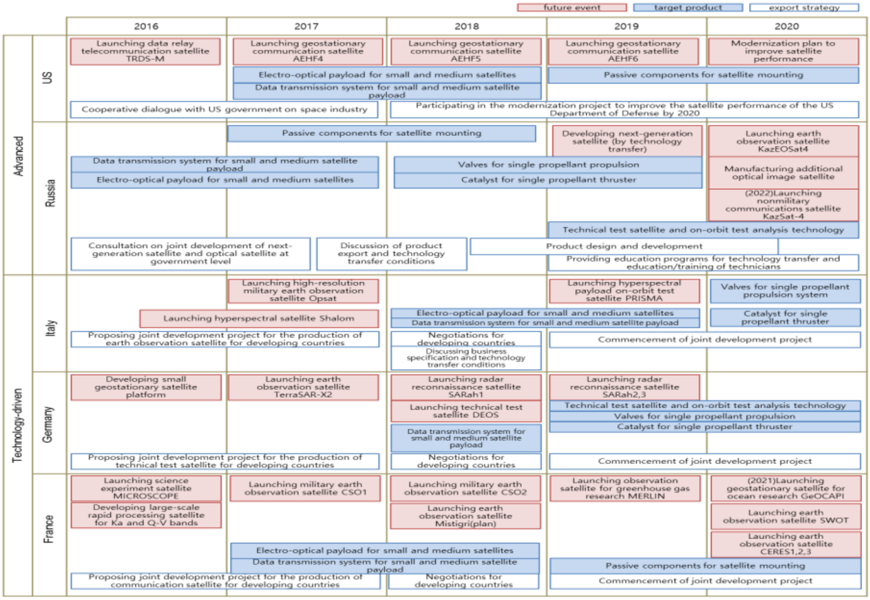


Figure 7 Export Roadmap: 'satellite manufacturing' Segment

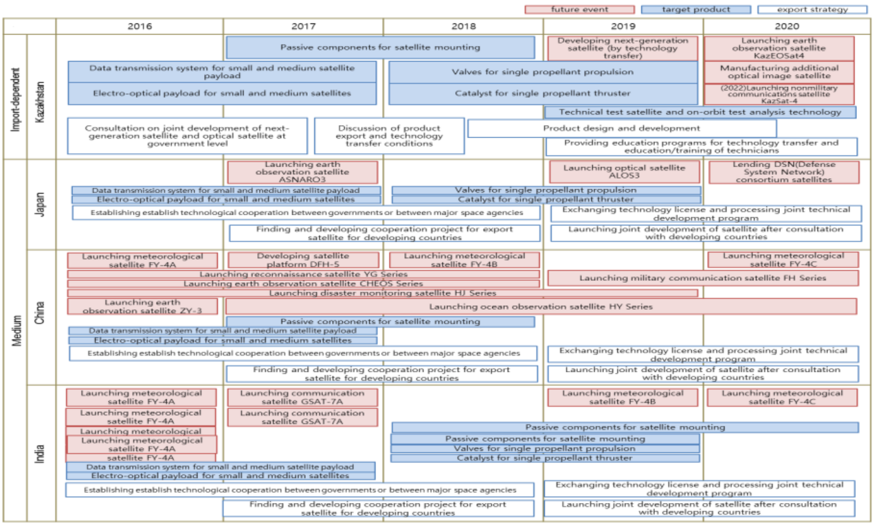


Figure 8 Export Roadmap: 'satellite manufacturing' Segment (cont.)

V. Concluding Remarks

This paper suggested an export roadmap for space products based on portfolio analysis. Roadmap exports of space products are too complex a challenge due to the need to connect a wide range of products and alternate target countries. Accordingly, this study offers an analysis of product marketability, technology competitiveness, and government policy plans, as well as systemic road map processes for developing primary and comprehensive strategies.

This paper has several implications. The roadmapping process and architecture proposed are customized to government-driven space product export and commercialization. The key metrics were suggested as product marketability and technology competitiveness, which were empirically measured based on R&D budget, RCA index, and patent applications. The portfolio map with eight country types and strategic guidelines were suggested. Based on future policy plans, opportunistic target products and specific export strategies are mapped into the roadmap. The national-level TRM proposed in this research can provide industry-wide insights to determine directions to go forward. As the Korean government strategically focuses on incubating SMEs in the space industry, the export roadmaps can help policymakers and SMEs establish future export strategies and development directions in each specific segment. In the context of TRM for open innovation, the export roadmap suggested in this paper is related to technology commercialization, contributing to a practical roadmapping framework for inside-out type of open innovation. Compared to prior TRM studies that focus on outside-in technology sourcing, this research can widen the application area of TRM.

Despite the implication, there are several limitations and rooms for future research. First, the data used in this study are incomplete and need to supplement by a new data source. In this study, the UN database used to evaluate product marketability lacked detailed product classification, and the OECD and World Bank databases only had data from major countries. Some of the emerging countries were insufficient. The patent data used for evaluating technology competitiveness is also based on patents registered with the US Patent Office, causing a bias in assessing technologies in countries like Russia.

So further research needs to secure additional data sources such as the European Patent Office. In addition to the national policy events collected in this study, considering market trends in the state of private-led space product development is useful. Second, candidate countries should be expanded to other emerging nations. The 17 export candidate countries in this study were selected to consider quantitative criteria such as the size of the import market and qualitative measures such as relations with Korea. Therefore, it is necessary to develop indicators that can quantify political and diplomatic ties. The expansion of the countries will also be required as the space industry is growing in the global sphere.

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