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Source: Journal of International Logistics and Trade 2021; 19(4):197-210

Published by: Jungseok Research Institute of International Logistics and Trade, Inha University

DOI: <https://doi.org/10.24006/jilt.2021.19.4.197>

Journal of International Logistics and Trade is an official journal published by Jungseok Research Institute of International Logistics and Trade, Inha University, Korea. JILT welcomes manuscripts that advance the practice and science of logistics, trade, and other related fields.

Frequency: Quarterly (March, June, September, December)

Stable URL: <https://www.ejilt.org>

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Stable URL: <https://jrieng.inha.ac.kr>

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ARTICLE

US-China Competition from a Perspective of Global Product Network: Trends and Implications of Industrial Competitiveness between Countries Using Product Space Model

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Received August 24, 2021

Revised November 6, 2021

Accepted November 25, 2021

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Abstract This study aims to examine the trend of industrial competition between the US and China, which is the most crucial determinant in the future development of the global economy. For decades, the global economy has strengthened the global production network based on the division of labor between countries. Thus, the ripple effect of competition between the two countries should be analyzed in terms of the global production network. Therefore, this study uses the product space model, which explains the development process of industries with comparative advantage by country. We constructed the model based on the products of HS 4-digit code for the 2010–2019 period. The analysis results on the trend of the industrial competitiveness of major countries are as follows. First, the current industrial competitiveness of China is concentrated on low-tech industries. In the case of high-tech items, China shows a tendency of lower export sophistication compared to major manufacturing powerhouses such as Germany, the US, Japan, and Korea. Second, with respect to the possibility of a future industrial structure upgrade evaluated by density, the trend of China overtaking other manufacturing powerhouses is observed. As implied by the product space model, the advancement of the industrial structure through active participation in international trade enhances the industrial competitiveness. Therefore, the outcome of US-China industrial competition depends on who ensures more openness and industrial complexity.

Keywords Product space model, Product proximity, PRODY index, EXPY index, US-China competition

1. Introduction

Can China continue to climb the ladder of industrial upgrading by overcoming the industrial blockade strategy of the US? US-China competition began with Trump administration's the imposition of tariffs on goods from China and is expanding into industrial and technological competition under the Biden administration. In particular, the Biden administration presented rebuilding a global supply network excluding China as a definite goal¹. In accord with the policy goal of the US government, the main trend in US industrial policies will be the expansion of the domestic manufacturing base of the critical industries in the US and the construction of supply chains centered in US allies against China.

China is deemed to have successfully climbed the development ladder through technology acquisition in the process of market opening for foreign-invested companies and government-led strong industrial policies since its reform and opening-up

¹The White House released a 100-day review report on the supply chains of the U.S. in sectors such as semiconductors, batteries, core materials, and pharmaceuticals. The main content of the report is that China is an emerging economic powerhouse in these critical sectors, and the production and innovation capabilities of the US have been weakened. (The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-based Growth, 100-Day Reviews under Executive Order 14017*, June 2021).

policy in 1978 (Colotla et al. 2018; Deloitte 2016; Wei et al. 2016). The major factors that have contributed to China's economic success are considered to be manufacturing cost competitiveness based on cheap labor (Colotla et al. 2018), a long-term strategic policy system in which the central government, local governments, national research institutes, and companies participate (Chen and Naughton, 2016), participation in global value chains and technology acquisition by Chinese companies as a result of the increase of international trade (Zhang and Gallagher 2016), and 'innovative manufacturing' unique to Chinese companies (Nahm and Steinfeld 2014). The trend of China's increasing industrial competitiveness has also been confirmed in Deloitte's study (Deloitte 2016) on the global manufacturing competitiveness index² and a UNIDO report (UNIDO 2020) on the global manufacturing competitiveness³.

There are opposing views on the effects of US policies toward China. On the one hand, it is claimed that US policies would not control China's growth, would not affect the resolution of the US employment problem or the US trade deficit, but is likely to have a negative impact on both the US economy and the global economy (Hass and Denmark 2020; Huang and Smith 2020). On the other hand, it is argued that China would be relatively severely affected by US policies toward China. Generally, Freund et al. (2018), Itakura (2020), and Walmsley and Minor (2018), which quantitatively evaluated the effect of the tariff increase, which was a policy measure taken toward China by the Trump administration, found that the impact of tariff hikes on the decrease of China's economic growth rate was estimated to be relatively greater.

Regardless of these conflicting views, the US-China trade war is highly likely to lead to changes in the global production network. An empirical analysis of WTO (2020) showed that the increase of policy uncertainty due to the US-China trade war and resulting decreases of exports and investments have more significant negative impacts than the effects of retaliatory tariffs imposed by the two countries. Therefore, it is important to observe the effects of US-China competition in terms of competitiveness in the global production network rather than bilateral trade relations. The trends of changes in the product competitiveness of the US and China are likely to have a fundamental long-term impact on the two countries and the global production network.

This study examines the US-China competition in terms of the difference in industrial competitiveness between the two countries. More specifically, using the product space model proposed by Hidalgo et al. (2007), this study attempts to examine the industrial competitiveness and trend changes of each country in terms of the positions in the entire product network occupied by comparative advantage products of each country. In the current international trade system, all the countries in the world are closely connected to form a global value chain. Therefore, it can be used as an alternative research method to evaluate the industrial competitiveness of a country by the positions of specific product items in the global production network rather than the comparative advantage of the goods.

China achieved its economic growth in a short period of time, maintaining its strong competitiveness in the manufacturing sector. However, to evaluate China's industrial competitiveness and, in particular, its future competitiveness, it is required to analyze its position in the global production network. This is because the network positions of China's current competitive advantage products and that of the future comparative advantage products are crucial in evaluating China's industrial competitiveness.

In this context, this study aims to find answers to the following questions. First, what are critical products from the product space model perspectives? To answer this question, we look at the top 20 PRODY products from 2010 to 2019 and products with high EXPY contribution in the US and China. Second, when the industrial competitiveness of each country is evaluated using the product space model, what are the differences in industrial competitiveness between China, the US, and major countries and the trends of changes in the industrial competitiveness of the countries? To answer this question, we examine the visualization of the world trade product network, the top US-China's revealed comparative advantage (RCA) items using the proximity matrix, and the trend of changes in EXPY contribution by technology level and country. Third, is China likely to carry out its industrial upgrade successfully? In other words, this study seeks to predict the possibility of China's industrial upgrade compared with other major countries. To answer this question, we examine industries' density by country and technology level during the 2010–2019 period.

This study is organized as follows. Section 2 presents a literature review of related studies, and Section 3 offers primary analysis results, including the methodology of the product space model, data, and the proximity network. In Section 4, the

²China maintained the top position in 2010, 2013, and 2016 in the manufacturing competitiveness index based on a survey among the CEOs of global companies.

³Germany was ranked first, China second, Korea third, and the US fourth showing that China's competitiveness in manufacturing surpassed that of the US.

trends of changes in the industrial competitiveness of each country are examined by identifying the major products of each country and their positions in the product space model. In Section 5, the path and possibility of China's industrial upgrade are evaluated using the product space model, and the implications for the US-China trade war and major countries are derived in the final section.

2. Literature review

The 'Great Convergence', coined by Baldwin (2016), has driven a highly divided global production network. The core of the evolving global production network is China's active participation in world trade and US-China cooperation. In this context, the US-China competition can be analyzed from a global production network perspective. The global production network has been analyzed using the network analysis method in many studies, e.g., De Benedictis and Tajoli (2011), Hidalgo et al. (2007), Kim and Shin (2002), and Pacini et al. (2021). However, there is no network analysis study on the change of the global production network after the US-China trade war to the best of our knowledge. The lack of research updates may be due to the difficulty in constructing updated trade data. However, the product space model used in this study is an alternative methodology that allows for overcoming a lack of trade data.

The product space model is used to identify the relationship between industrial development, international trade, and economic growth in various ways. For example, the product space model is being applied in various fields such as the development potential and economic growth of industries with comparative advantage at the regional economic level rather than the national level (Cicerone et al. 2020; Lee and Park 2017), and comparative analysis of industrial competitiveness between Korea, China, and Japan (Lee and Son 2019), prediction of export industry patterns in a specific country (De La Cruz and Riker 2012), the development potential of specific industries such as green product by country (Hamwey et al. 2013), performance analysis on corporate innovation support policies at the micro-level export subsidies and policies (Desmarchelier et al. 2018). The product space model developed its theoretical system through the proposal of several important concepts. The model asserts that the centrality of a specific product with a comparative advantage in a country is a determinant of the country's economic development based on the network between products at the national level (Hausmann and Kilnager 2007; Hausmann et al. 2007; Hidalgo and Hausmann 2009; Hidalgo et al. 2007). For this analysis, Hidalgo et al. (2007) first established a product space model as a proximity network between products calculated by the conditional probability based on the RCA. The RCA is an index showing a certain country's relative advantage or disadvantage in a certain product. In a proximity network, more sophisticated products are located in densely connected cores.

In addition, Hidalgo et al. (2007) proposed a density conceptualizing the possibility of industrial development as an advanced product through the distance between products in the product network. Hidalgo et al. (2007) identified why developing countries challenge converging their income levels with developed countries by combining the proximity network and the density. The reasons are the initial location of the developing countries and their relatively long distance from the product network, hence proximity between difficult-to-reach products. Expanding this discussion, complexity is correlated with a country's income level, and deviations from this relationship are predictive measures of future growth (Ferrarini and Scaramozzino 2015; Hidalgo and Hausmann 2009).

In the same context, the basic assumption of the product space model is that the product basket with comparative advantage expressed as export products determines a country's economic growth. That is, in the context of "what you export matters", Hausmann et al. (2007) proposed the PRODY and EXPY indices. EXPY is the measure of the productivity level associated with a country's specialization pattern. Hausmann et al. (2007) showed that EXPY exerts an independent force on economic growth. Therefore, by combining the density of Hidalgo et al. (2007) and EXPY of Hausmann et al. (2007), it is possible to quantify both the reachability of a product combination in a country in the future and the sophistication level of these product combinations.

3. Product space model

In this study, we constructed a product space model for the 2010–2019 period, based on the HS 4-digit code item classification of the UN Comtrade database. The product space model is a model which attempts to merge international trade theory, economic growth theory, and network theory. In other words, the model is based on the hypothesis that the position in the product network given as the initial condition for a country determines the path of economic growth, based on the notion of traditional economics theory that international trade positively influences economic growth. In addition, the paths of comparative advantage products in the product network varied according to the income level facilitating a dynamic analysis of the process of the industrial

upgrade of a country.

Traditional trade theory emphasizes comparative advantage and production specialization as crucial factors for economic growth. Accumulated capital and enhanced technology with international trade enable the country to upgrade its industrial structure. In this sense, economic growth can be a continuous upgrade process of comparative advantage products through international trade. However, traditional trade theory does not specify the products with similar levels of capital intensity. Traditional trade theory assumes that different compositions between products with the same capital intensity homogeneous economic growth. Therefore, it does not consider the linkage between the products' combination and the industrial network structure of the country to the industrial upgrade and the economic growth. On the contrary, the product space model attempts to supplement the trade theory of traditional economics using network analysis techniques. First, Hidalgo et al. (2007) suggested the product space map that visualizes the network structure between products. Through this, it is possible to infer a country's future product space map. Second, through the PRODY index proposed by Hausmann et al. (2007), the sophistication level of each product on the product space map is quantified. Through this, it analyzes whether the composition of products in a country is advanced. Third, indicators that measure the complexity of the network in the product space map, such as density, are proposed (Hidalgo et al. 2007). These indicators enable quantifying the potentials of the process in which the product network complexity leads to the next growth stage. In other words, in the product space model, the higher the complexity of the country's products combination, the more potential to upgrade its industry, eventually, the higher potential of the economic growth.

As in the analogy given by Hidalgo et al. (2007), in a product space model, products are described as trees, and the entire industry is viewed as a forest consisting of trees. Monkeys live moving through trees by jumping from tree to tree. The feeding activity of monkeys (individual countries) is closely related to their initial positions. They can easily move between closely located trees but have difficulty moving between trees located at a great distance from each other. The product space model assumes that the industrial upgrade of individual countries is also likely to be affected by initial industries with comparative advantage and the network of nearby products. Individual countries also achieve industrial upgrades by starting from industries with comparative advantage determined by initial endowments and transitioning technological innovations and production activities from industries with comparative advantage to nearby industries.

Therefore, the crucial part of the product space model is the quantification of the degree of linkage between products. The proximity between products is represented as the conditional probability of the RCA based on exports (Hidalgo et al. 2007). A country is deemed to have a comparative advantage in a product once the RCA of the country in the good is greater than 1. The RCA of country i in product k , RCA_{ik} , is calculated as follows.

$$RCA_{ik} = \frac{X_{ik} / \sum_{j \in C} X_{ij}}{\sum_{j \in C} X_{jk} / \sum_{j \in C} \sum_{l \in P} X_{jl}} \quad (1)$$

where X_{ik} indicates the exports of product k in country i , C is the set of countries, and P is the set of products. The proximity between a pair of good k and k' , $\phi_{k,k'}$, is set as the minimum out of the two conditional probabilities of the RCA, defined as

$$\phi_{k,k'} = \min \{ \Pr(RCA_k \geq 1 | RCA_{k'} \geq 1), \Pr(RCA_{k'} \geq 1 | RCA_k \geq 1) \} \quad (2)$$

where $\Pr(RCA_k \geq 1)$ is the probability that the RCA of any country for product k is not less than 1. In addition to the network characteristics of products, the PRODY index proposed by Hausmann et al. (2007) is also used to measure the level of sophistication of an item. The PRODY index of item k , $PRODY_k$, is a weighted average of the Gross Domestic Product (GDP) per capita of the countries exporting the item, where the weights are the exporting countries' RCA indices for the item.

$$PRODY_k = \sum_{i \in C} RCA_{ik} Y_i \quad (3)$$

where Y_i represents GDP per capita of country i . Therefore, an item with a high share of exports of high-income countries has a high PRODY index. For example, if semiconductors account for a high proportion of the export of a high-income country, the PRODY index of semiconductors is calculated to be a high value.

After obtaining the PRODY index, we can obtain the level of the sophistication of a country's export basket, which is called

the EXPY index. The EXPY index of country i , $EXPY_i$, is a weighted average of the PRODY values with weight of a product given to the share of the product in the exports of the country, which is defined as follows.

$$EXPY_i = \sum_{k \in P} \frac{X_{ik}}{\sum_{j \in P} X_{ij}} PRODY_k \quad (4)$$

Countries exporting relatively more goods with a high PRODY index have a higher EXPY index. There is a close positive correlation between GDP per capita and the EXPY index, as can be found in Figure 1. In other words, in terms of international trade, high-income countries can be regarded as those intensively exporting products with a relatively higher PRODY index.

The EXPY contribution level of item k in country i , $EXPY_C_{ik}$, is defined as follows. The level is an element of EXPY index.

$$EXPY_C_{ik} = \frac{X_{ik}}{\sum_{j \in P} X_{ij}} PRODY_k \quad (5)$$

The EXPY contribution level (EXPY_C) of an item in a country represents how much the item contributes to the EXPY of the country. Thus, goods with a high EXPY_C have a relatively significant influence on determining a country's EXPY index. For example, even when a country exports semiconductors, if the export proportion of the item is very low, its contribution to the EXPY index would be low. On the other hand, if a country exports clothing with low value but the export proportion of the item is high, its contribution to the EXPY index would be very high. As a result, clothing is the main export item that determines the EXPY contribution level of the country.

On the other hand, using the product space model, the industries with future comparative advantage of the country can be predicted. Hidalgo et al. (2007) and Hausmann and Klinger (2007) proposed a density index to measure the possibilities of a country's transition to a specific product. The density index was introduced to measure how closely a country's export industries surround a specific industry, and based on the index values, industries with future comparative advantage of the country can be predicted. A higher density index of a product in a country indicates a higher probability for the country to have a comparative advantage for the product in the future. The density index of item k in country i , w_{ik} , is calculated as follows.

$$w_{ik} = \frac{\sum_{j \in P} X_{ij} \varphi_{jk}}{\sum_{j \in P} \varphi_{jk}} \quad (6)$$

Figure 1. Relationship between EXPY index and GDP per capita in 2010 and 2019.

Source: Authors' calculations based on World Development Indicators and UN Comtrade data.

4. Major products and trade trends based on the product space model

The most remarkable trend of PRODY in the world's top 20 items in the 2010–2019 period is the widening gap between high-tech and other industries as can be seen from Table 1. That is, the PRODY value of high-tech items is larger on average than that of other products. In particular, during the 2010–2019 period, the gap in PRODY values between high-tech items and other

Table 1. PRODY index of the world's top 20 exported items (2010–2019)

Rank	2010			2019			
	Code	Description	PRODY	Code	Description	PRODY	
1	2709	Petroleum oils and oils obtained from bituminous minerals, crude	31,454.8	2709	Petroleum oils and oils obtained from bituminous minerals, crude	28,555.5	
2	2710	Petroleum oils and oils obtained from bituminous minerals (excluding crude); preparations containing	22,834.7	9999	Commodities not elsewhere specified	41,922.8	
3	8703	Motor cars and other motor vehicles principally designed for the transport of persons, incl.	26,447.0	8703	Motor cars and other motor vehicles principally designed for the transport of persons, incl.	36,587.4	
4	9999	Commodities not elsewhere specified	35,877.9	8542	Electronic integrated circuits; parts thereof	44,988.1	
5	8542	Electronic integrated circuits; parts thereof	35,812.3	2710	Petroleum oils and oils obtained from bituminous minerals (excluding crude); preparations containing	27,576.7	
6	8517	Telephone sets, incl. telephones for cellular networks or for other wireless networks; other	31,304.6	8517	Telephone sets, incl. telephones for cellular networks or for other wireless networks; other	41,912.8	
7	8471	Automatic data-processing machines and units thereof; magnetic or optical readers, machines	24,758.5	8708	Parts and accessories for tractors, motor vehicles for the transport of ten or more persons,	35,943.4	
8	2711	Petroleum gas and other gaseous hydrocarbons	48,742.4	3004	Medicaments consisting of mixed or unmixed products for therapeutic or prophylactic uses, put	42,297.0	
9	8708	Parts and accessories for tractors, motor vehicles for the transport of ten or more persons,	25,505.6	8471	Automatic data-processing machines and units thereof; magnetic or optical readers, machines	36,480.9	
10	3004	Medicaments consisting of mixed or unmixed products for therapeutic or prophylactic uses, put	28,271.9	7108	Gold, incl. gold plated with platinum, unwrought or not further worked than semi-manufactured	13,699.9	
11	7108	Gold, incl. gold plated with platinum, unwrought or not further worked than semi-manufactured	8,016.5	2711	Petroleum gas and other gaseous hydrocarbons	46,681.4	
12	8473	Parts and accessories (other than covers, carrying cases and the like) suitable for use solely	28,507.0	3002	Human blood; animal blood prepared for therapeutic, prophylactic or diagnostic uses; antisera	63,961.8	
13	8541	Diodes, transistors and similar semiconductor devices; photosensitive semiconductor devices	28,982.2	8411	Turbojets, turbo-propellers and other gas turbines	49,775.3	
14	8901	Cruise ships, excursion boats, ferry-boats, cargo ships, barges and similar vessels for the	24,642.4	8704	Motor vehicles for the transport of goods, incl. chassis with engine and cab	30,039.1	
15	7102	Diamonds, whether or not worked, but not mounted or set (excluding unmounted stones for pick-up)	18,144.0	9018	Instruments and appliances used in medical, surgical, dental or veterinary sciences, incl.	36,605.6	
16	8528	Monitors and projectors, not incorporating television reception apparatus; reception apparatus	25,426.0	8544	Insulated "incl. enameled or anodized" wire, cable "incl. coaxial cable" and other insulated	18,333.3	
17	8443	Printing machinery used for printing by means of plates, cylinders and other printing components	32,424.8	8473	Parts and accessories (other than covers, carrying cases and the like) suitable for use solely	43,031.7	
18	2601	Iron ores and concentrates, incl. roasted iron pyrites	17,838.4	2601	Iron ores and concentrates, incl. roasted iron pyrites	21,057.5	
19	2701	Coal; briquettes, ovoids and similar solid fuels manufactured from coal	20,481.0	7113	Articles of jewelry and parts thereof, of precious metal or of metal clad with precious metal	49,709.5	
20	9013	Liquid crystal devices not constituting articles provided for more specifically in other heading	29,540.1	8541	Diodes, transistors and similar semiconductor devices; photosensitive semiconductor devices	39,570.3	
Average		All	27,250.6	Average		All	37,436.5
		High-tech	29,075.3			High-tech	41,695.7
		Non-high-tech	26,034.1			Non-high-tech	33,177.3

Source: Authors' calculations based on International Trade Center's trade map and UN Comtrade data.

Note: Numbers in parentheses indicate percentile values and products of the shaded color are classified as high-tech products based on Lall (2000). The products classification is presented in Appendix 1.

items widened further. This trend implies that countries with high-income levels have strengthened their tendency to focus on exporting high-tech products. For example, the PRODY value of IC parts (8542) rises significantly from 35,812.3 in 2010 to 44,988.1 in 2019. In addition, products such as medical and related products (Code 3004, 3002, 9018) were first included in the top 20 items in the world trade, and all of these products have comparably high PRODY values.

The changes in the export competitiveness of major countries can be estimated from their EXPY indices during the 2010–2019 period, as depicted in Figure 2. The countries with the highest EXPY index are Japan and Germany, showing that the two countries have maintained the highest competitiveness in manufacturing for the past ten years. Korea's EXPY index has also surpassed that of the US since 2018, indicating that Korea is exporting relatively higher value-added items. The most noticeable change in the EXPY index in the past decade was a significant rise in the EXPY index shown by China and Vietnam.

As the top 20 EXPY_C contribution items, there is a difference in diversity in China and US (Table 2). China's top 20 EXPY_C items are concentrated on IT products (8525, 8471, 8542, 8517, 8473, 8541, 8504, 8543, 8516, 8518) and final consumer goods (9503, 4202, 9405, 9403, 7113). On the other hand, in the US, petroleum products (2710, 2709, 2711, 3901), pharmaceutical products and facilities (3002, 9018, 3004, 9021), facilities and parts (8479, 9020, 9027), IT products (8542, 8525, 8471, 8473), automobiles and related parts (8703, 8704), etc. are in the top 20 items.

Figure 3 shows the visualization of the proximity matrix obtained based on the HS 4-digit code of the UN Comtrade Database.

Figure 2. EXPY index of major countries for the 2010–2019 period.

Source: Authors' calculations based on World Development Indicators and UN Comtrade data.

Figure 3. Proximity network in 2019 classified by the method of Lall (2000).

Table 2. EXPY contribution level of China and US Top 20 exported goods (2010–2019)

China			US		
Code	Description	EXPY_C	Code	Description	EXPY_C
8525	Radio and TV transmitters, television cameras	3,649	9999	Commodities not elsewhere specified	4,435
8471	Automatic data processing machines (computers)	2,435	2710	Oils petroleum, bituminous, distillates, except crude	1,468
8542	Electronic integrated circuits and micro assemblies	1,865	8703	Motor vehicles for transport of persons (except buses)	1,250
8517	Electric apparatus for line telephony, telegraphy	833	2709	Petroleum oils, oils from bituminous minerals, crude	1,134
8473	Parts, accessories, except covers, for office machines	564	8542	Electronic integrated circuits and micro assemblies	1,104
8541	Diodes, transistors, semi-conductors, etc.	548	3002	Blood, antisera, vaccines, toxins and cultures	1,006
8708	Parts and accessories for motor vehicles	484	8708	Parts and accessories for motor vehicles	940
9503	Other toys, scale models, puzzles, etc.	451	8525	Radio and TV transmitters, television cameras	907
4202	Trunks, suit-cases, camera cases, handbags, etc.	436	2711	Petroleum gases and other gaseous hydrocarbons	867
2710	Oils petroleum, bituminous, distillates, except crude	423	9018	Instruments etc. for medical, surgical, dental, etc. use	662
9405	Lamps and lighting fittings, illuminated signs, etc.	400	8471	Automatic data processing machines (computers)	624
3926	Plastic articles n.e.s.	396	3004	Medicaments, therapeutic, prophylactic use, in dosage	588
8504	Electric transformers, static converters and rectifiers	385	8473	Parts, accessories, except covers, for office machines	437
9013	Liquid crystal devices, lasers, optical appliances n.e.s.	353	8479	Machines nes having individual functions	386
8543	Electrical machinery and apparatus, n.e.s.	337	9010	Equipment for photographic laboratories n.e.s.	360
9403	Other furniture and parts thereof	301	8481	Taps, cocks, valves for pipes, tanks, boilers, etc.	326
8481	Taps, cocks, valves for pipes, tanks, boilers, etc.	288	8704	Motor vehicles for the transport of goods	312
8516	Electric equipment with heating element, domestic, etc.	285	9027	Equipment for physical and chemical analysis	304
7113	Jewelry and parts, containing precious metal	265	9021	Orthopedic appliances	295
8518	Audio-electronic equipment, except recording devices	264	3901	Polymers of ethylene, in primary forms	289
Sum		14,962	Sum		17,694

Note: (%) indicated the proportion of the product in China's total EXPY. Products in the shaded colour are high-tech products according to the classification of Lall (2000).

In addition, each item group was visualized with a different color, based on the Lall (2000)'s technological classification of products of low, medium, and high. The network in Figure 3 was visualized using the multilevel layout algorithm of Yifan (2005)⁴. In the figure, the size of the node means centrality. Nodes with high centrality are located in the center of the network and thus significantly influence other industries. This visualization showed that high and medium-tech items are clustered to some degree and concentrated in the center area in the network. In Figure 4, high technology industries are clustered in the center of the network.

Figure 5 shows the locations of items with RCA of the US and China in 2010 and 2019 in the visualized product space network. The size of nodes in Figure 5 indicates RCA indices. China is shown to have items with RCA in all areas, encompassing items in the periphery area and high-tech items in the core area. Especially in 2019, items with higher RCA are relatively more concentrated in the core area. These results imply that China maintains a comparative export advantage in high-tech industries and low-tech, peripherally located products. The visualization is consistent with the trend of the top 20 EXPY contribution items in Table 2.

⁴The force-directed graph algorithm facilitates clustering while minimizing distances between nodes. As a result, Euclidean distance is approximately proportional to the geodesic distance between two nodes. That is, this algorithm tries to represent the ideal distance between nodes that aren't adjacent to each other.

Figure 4. Locations of the high-tech products classified by the method of Lall (2000).

Figure 5. Positions of China and US in the product space.

5. China's industrial upgrade

As in the analogy of Hidalgo et al. (2007), the proximity network of products can be envisioned as a forest comprised of the

trees of products as described above. At this time, it may be possible to quantify the possibility upgrading of the industrial structure of each country by obtaining the relative value for the possibility that monkeys can move from the first tree to another tree. For this purpose, the production path index (PATH) is first calculated. The PATH index is the sum of paths between all trees in a forest. In other words, it is the sum of all proximities of the product space network of a country. Therefore, the PATH index for each country is a constant. Then, to estimate the possibility of export sophistication of a specific item, density is calculated by dividing the sum of proximities connected to the specific item by the PATH index and normalizing the quantity. The density measures the average proximity of a new product to a country's current production network (Hidalgo et al. 2007). Therefore, density is a quantified value of a country's possibility of accessing other industries in the current product network. This concept is based on the hypothesis that the complexity of products with comparative advantage of each country determined the income level (Hidalgo and Hausmann 2009). Another hypothesis underlying the notion is that a high diversity of products with comparative advantage of each country and exporting items with low ubiquity are linked to economic growth, i.e., the process of increasing economic complexity is economic growth.

In addition, this approach is consistent with the previous study finding that proximity and density contribute to export sophistication (Kali et al. 2013). It also agrees with Poncet and de Waldemar's (2015) results using actual data of Chinese companies. Poncet and de Waldemar (2015) found that the density of links between products generates export-enhancing spillovers, which means that the intra-regional density level contributes to the growth of exports.

Major countries' average trends of EXPY_C representing current industrial competitiveness and density indicating the possibility of the industrial upgrade were examined by classifying industries into low-, medium-, and high-tech industries (Figure 6). As a result, it was found that Germany consistently maintained competitiveness in high-tech industries, Korea in medium-tech industries, and China in low-tech industries during the 2010–2019 period. However, in high- and medium-tech industries, China has consistently shown a lower competitiveness level compared to major countries. On the other hand, in the trend of changes in density, which indicates the possibility of an industrial upgrade, China showed a very high level of competitiveness in low-tech industries. The interesting point is that China has begun to show the level of competitiveness higher than that of the US, even in medium- and high-tech industries since the mid-2010s.

Semiconductors (8542), a key item in US-China trade war, are a representative high-tech item and a fiercely competitive item in US-China industrial competition. For the 8542 item, the level of competitiveness of China, as evaluated by EXPY_C, is low. On the other hand, with respect to future competitiveness, which is indicated by density, China has maintained the top

Figure 6. Average EXPY_C and average density of major countries by technological level during the 2010–2019 period.

Source: Authors' calculations based on UN Comtrade data.

Table 3. EXPY_C and density of semiconductors (8542) by country

		2010	2012	2014	2016	2019
EXPY_C	US	1,065 (10)	747 (12)	786 (12)	1,000 (13)	1,104 (13)
	China	690 (11)	886 (11)	976 (11)	1,233 (11)	1,865 (9)
	Korea	2,912 (6)	2,508 (7)	3,292 (6)	4,365 (5)	6,565 (5)
	Japan	1,610 (7)	1,275 (9)	1,354 (9)	1,548 (9)	1,778 (10)
	Germany	301 (15)	263 (17)	349 (15)	389 (15)	458 (16)
Density	US	0.53 (1)	0.45 (2)	0.35 (6)	0.34 (6)	0.32 (8)
	China	0.47 (3)	0.57 (1)	0.63 (1)	0.62 (1)	0.63 (1)
	Korea	0.34 (9)	0.32 (10)	0.34 (7)	0.34 (7)	0.36 (5)
	Japan	0.45 (4)	0.43 (4)	0.45 (2)	0.42 (2)	0.46 (2)
	Germany	0.47 (2)	0.45 (3)	0.42 (3)	0.39 (3)	0.39 (3)

Source: Authors' calculations based on UN Comtrade data.

Note: Numbers in parentheses represent global rankings.

position since 2012 (Table 3). Naturally, it is necessary to take into account the fact that since the HS 4-digit code, which is a broad category of items, was used, products of very different technological levels are included even in the category of semiconductors. Also, there is a need to consider that a significant part of China's exports in the high-tech industries are produced by foreign-invested companies in China. It is also necessary to consider the fact that an aggressive firms' innovation capability policy of the Chinese government enabled China to overcome the development trap in its exported goods, as suggested by the results of Desmarchelier et al. (2018), who converted a product space model into an agent-based model. However, even when these several factors are taken into account, it is indisputable that China has shown comparative advantage in production and exports in many high-tech industrial sectors and demonstrated a remarkable trend of technological development.

6. Concluding remarks

This study evaluated the industrial competitiveness levels of major countries, including the US and China, using the product space model. This practical analysis tool can analyze international trade, economic growth, and industrial development. For this purpose, this study constructed product proximity network, PRODY index, EXPY index, Density index for the 2010–2019 period. Using these indices, this study analyzed the trends of industrial competitiveness and future industrial competitiveness of major manufacturing countries such as the United States, China, Germany, Japan, and Korea during the 2010–2019 period. Major implications for the analysis are derived as follows.

First, China's export sophistication trend was prominently observed. The network visualization, taking into account technological levels, showed that China's main export items are located in the periphery area of the product network. Still, China entered the middle- and high-tech products in the core area to a considerable degree during the 2010–2019 period. China's possibility of industrial upgrade, which was assessed by the density of the product network, was shown to have already surpassed that of the US in 2018. Second, despite the possibility of China's export sophistication, its current industrial competitiveness is concentrated in low-tech industries. As for high-tech items, China has shown a trend of lower export sophistication, compared to major manufacturing powerhouses such as Germany, the US, Japan and Korea.

Since the product space model is based on the comparative advantage represented by exports, it may lead to overestimating the competitiveness of countries with a relatively high proportion of manufacturing and thus underestimating the competitiveness of service and R&D powerhouses such as the US. In addition, it may distort the competitiveness of each country in high-tech industries that depend on the competitiveness of specific items due to the product classification based on the broad categories of the HS 4-digit code. Nevertheless, it is unquestionable that China has demonstrated its export competitiveness in various industrial sectors in the past decade and has continued to increase the complexity of its industrial structure, showing a transition from the past economic structure dependent on labor-intensive industries. In addition, it is also a distinct trend that China's level of density has already approximated the levels of major manufacturing powerhouses since the mid-2010s, increasing the possibility of China's industrial upgrade in the field of high-tech industries.

These trends of China's export sophistication and industrial upgrade are sufficient factors to agitate the US and trigger the

US-China trade war. However, as implied by studies based on the trade-growth theory, including the product space model proposed by Hidalgo et al. (2007), a country's industrial competitiveness can be enhanced only by the evolution of industrial structure through participation in international trade. Therefore, China's responses to US-China industrial competition should be implemented to ensure further openness and industrial complexity. In this context, the current dual circulation strategy of the Chinese government should also be premised on active participation in international trade.

Hence, this study can draw implications for the widespread system competition between the US and China. The determining factors on the US-China system competition are continuous economic growth and industry competitiveness. China postures the world's second-largest economy after entering World Trade Organization, which will boost economic exchanges between countries and expand its advantage in various industries as suggested by the product space model. In the same context, it will guarantee a long-term systemic advantage for countries that maintain openness and expand the diversity of industries.

This research can be extended in several directions. First, a product space model was established through industrial classification of HS 4-digit in this study. However, to reflect more correctly the global division of labor system, it is needed to use a more divided industry classification such as HS 6-digit to build a product space model focusing on a specific industry such as IT industry. Second, it is meaningful to utilize the ubiquity and sophistication indices that can better reflect the complexity of each country's industry.

Acknowledgements

This work was supported by Global Research Network program through the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2017S1A2A2041812).

References

- Baldwin, R., 2016. *The Great Convergence: Information Technology and the New Globalization*. The Belknap Press of Harvard University Press, Cambridge, MA.
- Chen, L., Naughton, B., 2016. A dynamic China model: the co-evolution of economics and politics in China. *Journal of Contemporary China* 26(103), 1-17.
- Cicerone, G., McCann, P., Venhorst, V. A., 2020. Promoting regional growth and innovation: Relatedness, revealed comparative advantage and the product space. *Journal of Economic Geography* 20, 293-316.
- Colotla, I., Zhou, Y., Wong, J., Walters, J., Rose, J., Maecker, L., 2018. China's next leap in manufacturing. Boston Consulting Group. Available at: <https://www.bcg.com/publications/2018/china-next-leap-in-manufacturing>
- De Benedictis, L., Tajoli, L., 2011. The world trade network. *The World Economy* 34, 1417-1454.
- Deloitte, 2016. Global manufacturing competitiveness index. Available at: <https://www2.deloitte.com/global/en/pages/manufacturing/articles/global-manufacturing-competitiveness-index.html>
- De La Cruz, J., Riker, D., 2012. *Product Space Analysis of the Exports of Brazil*. U.S. International Trade Commission, Washington, DC.
- Desmarchelier, B., Regis, P. J., Salike, N., 2018. Product space and the development of nations: A model of product diversification. *Journal of Economic Behavior & Organization* 145, 34-51.
- Ferrarini, B., Scaramozzino, P., 2015. The product space revisited: China's trade profile, the world economy. *Wiley Blackwell* 38(9), 1368-1386.
- Freund, C., Ferrantino, M., Maliszewska, M., Ruta, M., 2018. Impacts on Global Trade and Income of Current Trade Disputes. MTI Practice Notes. World Bank, Washington, DC.
- Hass, R., Denmark, A. M., 2020. More pain than gain: How the U.S.-China trade war hurt America. Available at: <https://www.brookings.edu/blog/order-from-chaos/2020/08/07/more-pain-than-gain-how-the-us-china-trade-war-hurt-america/>
- Hamwey, R., Pacini, H., Assunção, L., 2013. Mapping green product spaces of nations. *The Journal of Environment & Development* 22, 155-168.
- Hausmann, R., Hwang, J., Rodrik, D., 2007. What you export matters. *Journal of Economic Growth* 12, 1-25.
- Hausmann, R., Klinger, B., 2007. The structure of the product space and the evolution of comparative advantage, CID Working Papers 146, Center for International Development at Harvard University.
- Hidalgo, C. A., Klinger, B., Barabási, A. L., Hausmann, R., 2007. The product space conditions the development of nations. *Science* 317, 482-487.

- Hidalgo, C. A., Hausmann, R., 2009. The building blocks of economic complexity. *Proceedings of the National Academy of Sciences of the United States of America* 106, 10570-10575.
- Huang, Y., Smith, J., 2020. In the U.S.-China Trade War, New Supply Chains Rattle Markets. *Carnegie Endowment for International Peace*, Washington, DC.
- Itakura, K., 2020. Evaluating the impact of the US-China trade war. *Asian Economic Policy Review* 15, 77-93.
- Kali, R., Reyes, J., McGee, J., Shirrell, S., 2013. Growth networks. *Journal of Development Economics* 101, 216-227.
- Kim, S. M., Shin, E. H., 2002. A longitudinal analysis of globalization and regionalization in international trade: A social network approach. *Social Forces* 81, 445-468.
- Lall, S., 2000. The technological structure and performance of developing country manufactured exports, 1985-98. *Oxford Development Studies*. 28. 337-369.
- Lee, B., Park, J., 2017. Structural transformation of exports in a product space model: The case of Daegu-Gyeongbuk province, Korea. *Korea Trade Review* 42, 47-67.
- Lee, B., Son, W., 2019. A Comparative Analysis of Structural Changes of Korea, China, and Japan in Product Space, Structural Transformation of Exports in a Product Space. *Korea Institute for International Economic Policy*, Sejong, Korea.
- Nahm, J., Steinfeld, E. S., 2014. Scale-up nation: China's specialization in innovative manufacturing. *World Development* 54, 288-300.
- Pacini, H., Shi, G., Sanches-Pereira, A., da Silva Filho, A. C., 2021. Network analysis of international trade in plastic scrap. *Sustainable Production and Consumption* 27, 203-216.
- Poncet, S., de Waldemar, F. S., 2015. Product relatedness and firm exports in China. *The World Bank Economic Review* 29, 579-605.
- UNIDO, 2020. *Competitive Industrial Performance Report 2020*. United Nations Industrial Development Organization, Vienna, Austria.
- Walmsley, T., Minor, P., 2018. Estimated impacts of US sections 232 and 301 trade actions on the US and global economies: A supply chain prospective 2018-2030. *ImpactECON*, Boulder, CO.
- Wei, S. J., Xie, Z., Zhang, X., 2016. From "Made in China" to "Innovated in China": Necessity, prospect and challenges. *Journal of Economic Perspectives* 31, 49-70.
- WTO, 2020. An economic analysis of the US-China trade conflict. *Staff Working Papers ERSD-2-2*.
- Hu, Y., 2005. Efficient and high quality force-directed graph drawing. *Mathematica Journal* 10, 37-71.
- Zhang, F., Gallagher, K.S., 2016. Innovation and technology transfer through global value chains: evidence from China's PV Industry. *Energy Policy* 94, 191-203.

Appendix 1. Technology classification based on Lall (2000)

Classification	Code	Description
Low technology	2601	Iron ores and concentrates, roasted iron pyrites
	2709	Petroleum oils, oils from bituminous minerals, crude
	2710	Oils petroleum, bituminous, distillates, except crude
	2711	Petroleum gases and other gaseous hydrocarbons
	4202	Trunks, suitcases, camera cases, handbags, etc.
	7113	Jewelry and parts, containing precious metal
	9503	Other toys, scale models, puzzles, etc.
Medium technology	8443	Printing and ancillary machinery
	8471	Automatic data processing machines (computers)
	8525	Radio and TV transmitters, television cameras
	8703	Motor vehicles for transport of persons (except buses)
	8704	Motor vehicles for the transport of goods
	8708	Parts and accessories for motor vehicles
	8901	Passenger and goods transport ships, boats
High technology	3002	Blood, antisera, vaccines, toxins and cultures
	3004	Medicaments, therapeutic, prophylactic use, in dosage
	8411	Turbojets, turbo-propellers/other gas turbine engines
	8471	Automatic data processing machines (computers)
	8473	Parts, accessories, except covers, for office machines
	8517	Electric apparatus for line telephony, telegraphy
	8528	Television receivers, video monitors, projectors
	8541	Diodes, transistors, semi-conductors, etc.
	8542	Electronic integrated circuits and micro-assemblies
	8544	Insulated wire and cable, optical fiber cable
	9013	Liquid crystal devices, lasers, optical appliances
Unclassified products	9018	Instruments etc. for medical, surgical, dental, etc. use
	7108	Gold, unwrought, semi-manufactured, powder form
	9999	Commodities not elsewhere specified