Development patterns of economic complexity and diversification:

From co-evolutionary perspective of production and innovation

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From co-evolutionary perspective of production and innovation

지도교수 이정동

이 논문을 공학박사학위 논문으로 제출함

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협동과정 기술경영경제정책 전공

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위 원 장 **Jörn Altmann** (인)

부위원장 이 정 동 (인)

위 원 구 윤 모 (인)

위 원 박 상 욱 (인)

위 원 백 철 우 (인)

Abstract

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Wonsub Eum
Technology Management, Economic, and Policy Program
The Graduate School
Seoul National University

Studies on economic development have recognized the technological innovation as a key factor of economic growth, in addition to traditional factors including increase in labor and accumulation in capital stocks. More recent studies put more focus on the difference in complexity of industrial structures of countries and its effect on different growth patterns. Previous studies focusing on the technological innovation or the industrial structure implicitly acknowledge the importance and interdependence of each other, and boundaries between production and innovation often got blurred. However, there has been no study that link the two fields explicitly.

This study starts with a hypothesis that the economic complexification, or industrial development is not a smooth transition process but rather involves several uneven jumps during the accumulation and diversification processes of production and technological capability. This study aims to identify the path-dependent patterns between production and technological capabilities across countries, and provide a multilateral capability perspective to current studies. The following chapters approach the question of economic complexity from co-evolutionary perspective on the product space and technology space based on international export and patent data.

Chapter 2 studies the jumps and traps that a country faces during its industrial development, and sets up a framework to understand the growth stages of a country from an evolutionary point of view. In particular, this chapter argues that a successful country evolves through three stages of coevolution between closely interconnected production and knowledge. These coevolution stages include frequent jumps and traps during industrial diversification, rather than smooth transitions following the comparative advantage of countries. Analyses through linkage between the product space and the technology space show the co-evolutionary paths of production capability and knowledge capability. A case study of Korean development experience, which has gone through the coevolution stages suggested in this chapter during the past decades, identifies the jumps and traps during industrial development and suggests a successful path of diversification.

Chapter 3 investigates whether production capabilities fostered the development of new technological capabilities at the national level. This chapter adopts the concept of ‘product space’ and ‘technology space’ for network analysis, and analyzes whether the current production capability in related technologies influences the future technological capability. The main comparative analysis is based on export data and international patent data from 1980 to 2005, and ALP (Algorithmic Links with Probabilities) concordance to link production and innovation. The results show that past production advantages of a country plays a significant role in the emergence of new technological advantages. This finding suggests that current production capability provides evolution paths not only to new products, but also to technological innovations.

Chapter 4 examines the relationship between patterns of national-level industrial diversification and core-technology competence of countries. Industrial diversification measured by changes in export structure represents what a country does, and knowledge or technological competence measured by patent structure represents what a country knows. Similar relationship has been suggested by the firm dynamics theories, and this chapter expands the previous firm-level diversification literature into national-level co-evolution of production and technological competence. This chapter uses international export and patent data linked by the ALP concordance matrix, from 1980 through 2010. The analysis shows that the change in the degree of industrial diversification is positively related with their current technological competence, and more specifically, that technological competence is the driver of unrelated diversification. These findings support the previous studies on the importance of technological competence in diversification, and suggests an alternative way of interpreting unrelated diversification by considering technological competence as a key factor.

Chapter 5 studies trends in the evolution of capability and economic complexity, along with the specialization options of countries by analyzing the changes in export structures at the national level. This chapter contrasts the specialization options of countries at different economic stages and shows their dynamic changes across years. The findings show that current research on specialization patterns of countries may not be applicable to developing countries because they do not include possible aims with both high complexity and similarity to the current production structure. As a result, developing countries can only take either the 'high-risk high-return' or 'low-risk low-return' tracks, but not the 'low-risk high-return' tracks that developed countries aim for. This chapter suggests a multilateral path between product space and knowledge space to understand the driving forces of specialization. Based on a comparative analysis of countries, the results suggest that effects of production and knowledge capability on development of a new capability vary by the income levels of countries. The findings give policy implications to developing countries that complexity upgrading requires understanding of both production and knowledge structures.

In summary, the main implication of this study is that production and technological capability are interdependent, and coevolve as the economy gets more complex. The findings support that technological capability is an indispensable factor in explaining the diversification pattern, and that production capability promotes technological innovation. Specifically, the effects of two capabilities on each other show

different patterns by the income level of countries. Based on these findings, this study provides a unique industrial and innovation policy implication that the current production and technological capability should be a key guidance to strategic technological and industrial diversification, respectively.

Keywords: Economic Complexity; Diversification; Path-dependence; Capabilities; Comparative Advantage; Product Space

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Chapter 1. Introduction

1.1 Motivation and objectives

The aim of this study is to examine the co-evolutionary patterns of production and technological capabilities during the economic complexification, or following development. Here, this study considers the production capability as the aggregation of comparative advantage in exports (Balassa, 1965), and uses the export patterns as a proxy to represent the industrial structures of countries. On the other hand, the technological capability or innovation capability as the aggregation of comparative advantage in international patents (Soete, 1987), and patent portfolio as a proxy to represent the technological structures of countries. This study focuses on Ricardian comparative advantage that refers to specific activities, rather than Smithian specialization coming from the depth of specialization (Laursen, 2000). Also, economic complexification is treated analogous to economic development (Hausmann et al., 2014; Hidalgo & Hausmann, 2009), measured by the complexity of products in countries' export baskets and changes as countries specialize and diversify (Hidalgo et al., 2007). Diversification is defined as acquiring a new comparative advantage, which is measured by revealed comparative advantage, in a product or technology class that a country did not have comparative advantage in the previous period.

This study starts from the Schumpeterian perspective on economic growth considering technology as a main driver of economic development (Schumpeter, 1912). However, often technology has been considered as an exogenous variable, or black box (Rosenberg, 1982), and not received much attention in many economic studies. In fact, unlike other economic theory studies, international trade studies already have considered technology as a key factor of international trade flows and international competitiveness (Dosi & Soete, 1990). Still, only a number of countries are actively developing new technology (Petralia et al., 2017), and the technological gap between countries is not getting reduced. Countries in North America, Europe, and some Asian countries are responsible for most of the international patents granted, and this trend has continued for decades. Therefore, there is a need to highlight the importance of technology in economic development, yet in different contexts for countries at different economic stages with different technological capability (Kim, 1997; Lall, 2000a).

This gap among the countries is not only observed in technological capability, but also in their economic complexity representing the degree of complexity in their product baskets. Countries already capable of producing complex products with various embedded knowledge are likely to advance to more complex products, whereas countries specializing in simple products are less likely to advance to them (Hidalgo et al., 2007). Strong path-dependence in capability building leads us to more pessimistic anticipation for less developed countries, since changes in economic structure are difficult to be achieved.

Let us go back to Schumpeterian theory of creative destruction suggesting that development is the result of radical changes in the economy, and new opportunities to gain competitiveness emerge as former sources of comparative advantage fade out and new chances of gaining comparative advantage rise (Levinthal, 1992). This argument seems to contradict the previous evolutionary studies based on path-dependence, that countries are less likely to transform their current structure. To fill this gap, this study tries to explain the jumps – or the radical changes – and traps – or the difficulties – that countries face during different stages of economic development, from path-dependent perspective.

If countries accumulate their capabilities following path-dependence, what can be the path? Studies on path-dependence until now have explained how countries accumulate their capabilities by explaining that the current set of capability leads the emergence of a similar capability. In other words, countries will produce a similar product to what they are currently producing, and get innovative ideas in a technology field that is similar to what they have already known. These arguments give us useful implications in product or technology specialization, yet do not include co-evolutionary link between production and innovation. The tie between production and technology, and possibility of new production or technological capability arising from each other does not get enough attention in the previous studies. Often, countries find new export opportunity in what they have already known, and also develop technological advantage by years of production experience, even these opportunities seem path-defying, or unrelated to what they have been doing or knowing. These advances in seemingly unrelated activities are in fact not unrelated, yet rather strongly path-dependent from their current capability structure, but across the two different capability fields of production and technology. In this sense, some specific topics that need further researches are innovation from production (Berger, 2013) such as learning-by-doing (Lall, 2000a), and diversification from technological base (Miller, 2004).

In addition, they have limitation in explaining the accumulation of technological capabilities in developing countries, and explaining the different patterns of countries at different economic stages.

Based on the discussion above, this study reaches three research motivations. First, it tries to answer the questions on the co-evolutionary relationship between production and technological capability, especially in countries at different economic stages by providing empirical evidence. Second, it aims to enrich the current economic complexification and innovation theories on by suggesting path-dependence from multilateral paths across a two-way model of production and innovation. Lastly, it suggests an alternative approach to the recent studies on industry and technology specialization, to be applicable to both developed and developing countries.

1.2 Outline of the study

This study consists of six chapters to set up a conceptual framework and provide empirical evidence for the co-evolution of production and technological capabilities during economic development and complexification. **Figure 1-1** shows the structure of this study, which includes one chapter of conceptual framework for three stages of economic complexification and three chapters of empirical evidence for each stage. The rest of the study is aligned as follows.

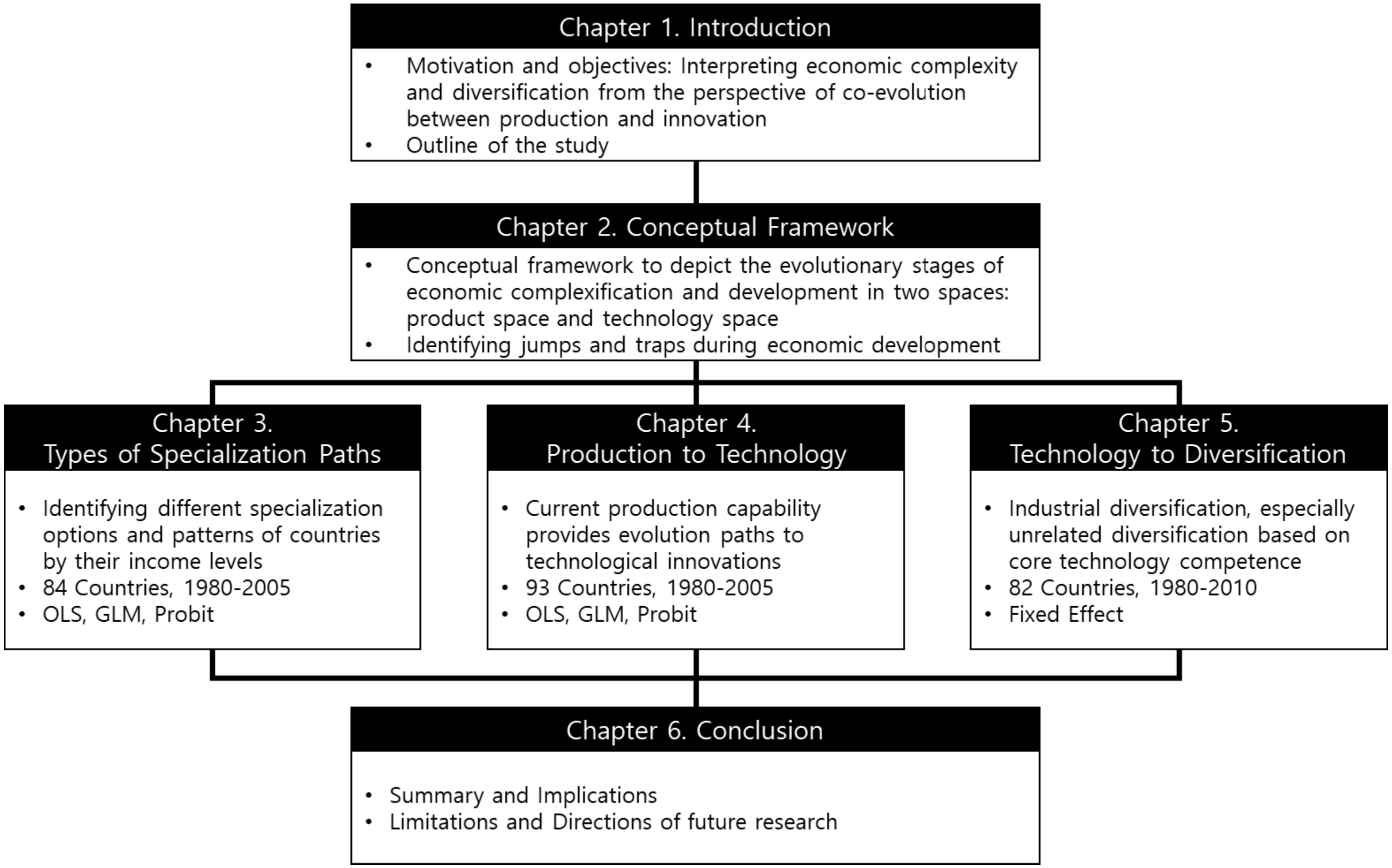


Figure 1-1. Outline of the study

Chapter 2 suggests three co-evolutionary stages of production and innovation during industrial development and economic complexification. It also identifies the jumps and traps during the stages, and builds a framework to understand the growth stages of a country from an evolutionary point of view. These coevolution stages explain the frequent jumps and traps that a country faces during complexification and diversification, in opposition to comparative advantage-following smooth transitions. Product space (Hidalgo et al., 2007) and technology space (Boschma et al., 2013) are adopted and linked together to show the production and innovation capability in a single network space, and a co-evolutionary path. A Korean case of economic development that has gone through the three stages of development follows, and provides historical evidence to identify the jumps and traps a country faces in different development stages.

Chapter 3 studies the relationship between current production capabilities and future development of new technological capabilities. Specifically, this section examines whether producing similar products lead to acquirement of technological advantage in the future, through linking the product space constructed based on the export data and technology space constructed based on the patent data. The analysis using a unique international panel dataset covering 1980 through 2005 supports that past production experience of a country significantly and positively influences the emergence of new technological advantages. This finding gives implication that there exists a path-dependence on the single product space – from production experience to future production advantage – but on a multilateral space of production and innovation.

Chapter 4 examines the relationship between core-technology competence of countries and national-level industrial diversification. Specifically, by decomposing the diversification into two types – related diversification and unrelated diversification – this study gives more attention to the factors of unrelated diversification. Industrial diversification is measured by the degree of export diversification, and technological competence is measured by the competence in patents of core technologies. By expanding the diversification studies from firm dynamics, this section tries to explain the national-level diversification patterns from the perspective of co-evolution of production and technological capability. The results show that the current technological competence positively influences the future change in the degree of industrial diversification, and especially the degree of unrelated diversification. These findings emphasize the role of technological capability in diversification in patenting countries, and provides an alternative rationale to unrelated diversification.

Chapter 5 points out the different specialization options of countries by their income levels, and suggests that countries at different development stages need different specialization or diversification strategies. Previous specialization studies, especially the recent smart specialization strategies have limitations in providing industrial or technological specialization paths to developing countries without an established industrial or technology basis. Under the smart specialization framework, these countries cannot aim for either high-return products or technologies because they are too risky, but only can aim for low-return products or technologies. By focusing on learning from production experience, or learning-by-doing (Lall, 2000a), production capability is included as one of the key factors in technological capability emergence in a country. Also, the influence of technology capability on future production capability is tested. The findings show different results by income levels of countries. The results show that in lower-income countries, production advantage of similar products leads to both production and technological advantage in the future, but technological advantage does not. In higher-income countries, production and technological advantage leads to future production advantage, but only technological advantage leads to future technological advantage. The findings give policy implications that specialization prescription to countries at different economic stages should focus on both production and knowledge structures.

Chapter 6 summarizes the main findings of the study from the perspective of co-evolution between production and innovation. Based on the theoretical and empirical analyses from the previous chapters, this chapter discusses the implications for policy and practice. Lastly, it concludes the study by mentioning the limitations of the study, and providing directions for future research.

Chapter 2. Understanding the jumps and traps in the industrial development process: Coevolution of production and knowledge

2.1 Introduction

Product sophistication and diversification are factors that are closely correlated with industrial and development (Rodrik, 2007). Countries seek to secure necessary technological capability to support the product diversification process, as industrial transformations inevitably involve processes of accumulation of knowledge and capabilities (Cimoli et al., 2008). Yet, these processes of sophistication and diversification are not automatic, and often needs intentional policy support for knowledge upgrading and product diversification (Mazzucato, 2013). This chapter tries to explain these processes through a national-level framework based on coevolution of production and knowledge.

In order to understand the process of product diversification, recent studies including Hidalgo et al. (2007) developed the concept of product space. Their study is based on the export data, using the conditional probability of co-occurrence to measure the relatedness among products. Product relatedness calculated by co-occurrence assumes that related products share certain common capabilities. Therefore, if two products are likely to be produced – or co-occurring – in a country, they are highly related. The product space analyses give useful implications to understanding of emergence of products in economies.

One implication is that new product emerges in the neighbourhood of existing products of an economy. This is in line with path-dependence characteristic of capability development (Martin and Sunley, 2006), and regards product diversification as a continuous and gradual process with high path-dependence. Also, higher economic performance is positively correlated with producing core products. These core products, namely machinery or chemicals, are at the centre of the network structure with many connections with other products. Hidalgo et al. (2007) illustrates countries as “monkeys colonizing the forest, occupying more trees, and moving especially into the more complex or fruitier ones” by traversing the trees with the neighbouring branches.

However, often in the real world, new products emerge far from the current set of products. We consider these as jumps, or the change in or addition to the industrial structure despite being less related with the current industrial portfolio. These jumps indicate the countries jumping across products as their industrial portfolios change, just as the monkeys jumping distances to exploit different trees. In other words, during jumps, countries redeploy their resources and capital to products that are different from what they have been exploiting (Ferrarini & Scaramozzino, 2015; Hidalgo et al., 2007; Zhu et al., 2017). This study argues that these path-defying diversification behaviours appear more often than the frequency expected by the path-dependent theory. Especially, the emergence of new products at the firm and sectoral level often come from somewhere distant from the existing portfolio. For example, there is the emergence of the steel industry in Korea in the early 1970, which has been an agricultural economy at the period. Recently, bio-similar business is expanding in the Korean pharmaceutical sector since the mid-2000s by Samsung Electronics which started as a sugar-trading company. These phenomena of new advantages emerging in products from distant sectors are hard to explain with the product space analysis, which is based on a firm path-dependence theory.

On the other hand, traps also appear more often than expected in the real world. Countries across different stages of development face traps, such as poverty traps (Baland and Francois, 1996; Bloom et al., 2003; Sachs et al., 2004) or middle-income traps (Liu et al., 2017; Radosevic and Yoruk, 2018; Vivarelli, 2016). In previous studies, a trap such as middle-income trap of a country is defined as a failure to upgrade the products in terms of sophistication and diversification, being locked in a low value-added function, and therefore a slowdown in economic development. Also recently, a concept of middle-innovation trap has been suggested (Lee et al., 2019), which is the difficulty in securing concept design capability despite of accumulating implementation capability. This study identifies these traps during economic development and complexification of countries, and additionally suggests another trap, or difficulty in advancing to new industries based on its current technological capability. Whereas the middle-income traps are more widely-used terms by economists and international institutions (Agénor et al., 2012; Eichengreen et al., 2013; Felipe et al., 2012), the other two traps need further discussions. As an example of a middle-innovation trap, automobile sector in Thailand has continuously failed to build up key component industry such as engine manufacturing. Despite the high co-occurrence probability between automobile assembly and car engine, assembly for decades did not lead to engine manufacturing in Thailand. With path-dependence on the product space, it is difficult to explain the reality where only few countries acquire capabilities and move on to more value-added core products, whereas many countries take much longer time or even fail to advance. Also, there exists a difficulty in diversifying products based on the current technological capability at national level, yet a number of successful firm-level cases such as Fujifilm advancing to bio-health and cosmetics based on its collagen technology suggest the possibility of escaping from this trap. These traps and jumps are not merely special cases, and they occur more often than expected. In order to explain these phenomena, we need a conceptual framework.

The objective of this study is to understand the jumps and traps in product diversification process. Specifically, this chapter approaches the industrial development process as a result of coevolution between production and technology, and considers technological capability as one of the key factors during product diversification or specialization. To analyse the relationship between production and technology – or product and knowledge – this study will utilize the concept of technology space along with product space.

The rest of the chapter is structured as follows. Section 2 covers the conceptual discussion on co-evolutionary process between production and technology. Section 3 introduces and defines the concepts of jumps and traps during stages of national development. Section 4 applies these concepts to historical case of Korea during industrial development process and provides interpretation of a successful development experience.

Section 5 concludes the chapter with a summary of the main arguments and provides policy implications.

2.2 Co-evolutionary process between production and knowledge

2.2.1 Theory of production and knowledge diversification

Classic economic theory tries to answer the question of what to produce and why to produce it from analyzing the fundamentals of countries, such as labor, capital, natural resources, and others including technologies and institutions. Specifically, according to Ricardian theory, what countries produce depend on the different productivity and following comparative advantages of them. On the other hand, Heckscher-Ohlin-Samuelson (HOS) model focuses more on the factor endowments of countries, and argues that countries specialize based on these endowments. Therefore, this model predicts that countries' diversification paths would produce and export the products that capture the advantages they have. If countries attempt to advance to production structure beyond the current endowments, these would be likely to fail and even slow down the economic performance (Hausmann et al., 2007). This logic is in line with the concept of lock-in, or path-dependence of innovation theories. (Arthur, 1989; Martin, 2010)

Theory on knowledge development also shows high interest in diversification and specialization patterns of regions and countries. It has been under debate whether a variety of knowledge or specialization of knowledge can lead to creativity and innovation – often referred to as Jacobs' externalities and Marshallian externalities, respectively (Caragliu et al., 2016; Feldman and Audretsch, 1999). More specifically, Jacobs' externalities are externalities coming from complementary knowledge and networks among diverse firms and people, adding a positive externality to economic knowledge. On the other side, Marshallian externalities are externalities closely linked with the specialization, and the knowledge spillover coming from better increased concentration inside specific regions. Empirical studies provide evidence from various industrial sectors and regions, yet the results remain inconclusive (Beaudry and Schiffauerova, 2009). Recent studies suggest that both Marshallian and Jacobs' externalities exist, yet differently in different context (Caragliu et al., 2016; Paci and Usai, 1999).

Nevertheless, many of these studies assume static economies of countries to explain specialization and diversification patterns (Boschma et al., 2015). To fill this gap, more recent studies have tried to incorporate dynamic nature of diversification in industrial structure and knowledge. For example, Hidalgo et al. (2007) started the discussion of observing diversification steps of a country through a network space analysis by constructing a product space. Following studies argue that a country is likely to acquire new capability in a product if the country is already producing similar, or related products (Bahar et al., 2014; Felipe et al., 2012; Hidalgo and Hausmann, 2009; Jun et al., 2017), and therefore countries producing the core products are likely to diversify easily than those producing the periphery products. The same pattern is also seen in service industry, where software services in core network position attract the most users (Kim et al., 2019) More specifically, previous studies suggest a path-dependence from capability accumulated through the history in determining the specialization or diversification of the future. Based on their argument, we can measure the distances between products and determine whether the products are close to or far from each other, and analyze whether the products are at the core or periphery of the product space. The core products have more relatedness with other core products, so having comparative advantage in producing the core products would lead to higher possibility to diversify. Relatedness between products may come from sharing similar labor, capital, institutions, or technologies (Hidalgo et al., 2007). Among them, this study suggests that high relatedness and following possibility of diversification stems from products sharing similar technological roots, and emphasizes the importance of co-evolutionary relationship between production and knowledge.

2.2.2 Stages of development based on co-evolution between production and knowledge

In understanding the development path of a developing country from its developing stage, we can refer to the seminal work by Kim (1997). Mainly focusing on the case studies from South Korean development experience, the author expanded Utterback (1994) and postulated that there are three stages of technological capability development for catching up countries – acquisition, assimilation, and generation. Whereas Kim (1997) focused on the technology transfer during different technological trajectories, this study analyzes production and knowledge during different industrial development stages. We distinguish product space and technology space, and each represents overall maps of national capability of production and technology, where each country can be plotted based on the sectors it has advantages on. The capabilities required for production and innovation are closely linked, but they should be distinguished because countries at different stages of development show different patterns of learning processes and capability evolution (Bell and Pavitt, 1993). **Figure 2-1** shows the co-evolutionary paths of production and knowledge of a country, and categorizes three transitions across the product and knowledge space: from P0 to P1, from P1 to T1, and from T1 to P2.

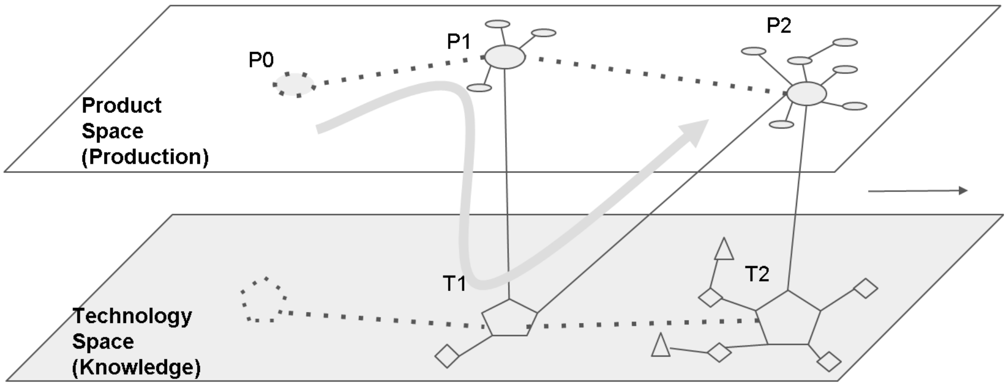


Figure 2-1. Coevolution of production and knowledge across product and technology space

P0→P1 Let us assume a country without comparative advantage in either production or knowledge. This country is located at the periphery of the product space, showing advantage in exporting less complex products such as crude materials and minerals, food and animals, and other natural resources. It does not have advantage in many core products.

Therefore, under path-dependence theory, this country has limited options of high value-added products to advance to. Also, it only has limited technological capability. Considering the widespread information asymmetry and coordination failure in the developing country (Rodrik, 2009), it would be difficult for this country to target and advance to a distant product from its current capability.

According to the Ricardian theory of comparative advantage in exports, this country can produce and export products even without knowledge. Most of the exported products are those do not require much knowledge or innovation capability, for example, raw materials and less sophisticated products with low value-added. Yet, a country can learn through its production experience and following exports, and accumulate some capitals to try diversification in its export portfolio. Exporters at during this transition stage depend on foreign sources for product innovation. Until they accumulate some experience from production to meet differentiated demands, it is cost effective and may even be necessary to depend on foreign buyers for product design technology (Westphal et al., 1981). As the country continues producing, it observes the production processes to learn how to produce more efficiently, often referred to as learning-by-doing (Arrow, 1962). The country can remember the production skills through years of production, regardless whether the fundamental technology came from external sources. At this stage, a country does not have enough capability to understand the technology behind production, but continuous production helps remembering “know-how” even without understanding “know-why.” (Lall, 2000)

Developed countries have strong path-dependence and experience strong stickiness (von Hippel, 1994) from what they were producing and innovating. Nevertheless, because a developing country's capability basis is relatively weak, there is a weaker path-dependence and are more likely to advance into less related products. Under several diversification options, some countries decide to closely follow its factor endowments and focus on labor-intensive products or products that use abundant resources in them. On the other side, some countries decide to try producing new products that are seemingly far from what they are capable of producing now. Although production of these new products are mostly assembly and still at low value-added in the global value chain, these countries get more experience with production stages of sophisticated products. Difference in export portfolio and starts to arise from these two types of countries. Because what a country can learn from remembering the production process differs by what a country produces, difference in learning also starts to arise.

P1→T1. A successful country that passed the first step from P0 to P1, after learning from the production experience, then can aim for 'know-why.' Know-why refers to the underlying knowledge of principles behind the products, for example product design or working mechanisms, as opposed to 'know-how,' a set of practical skills which are more related and limited to producing with higher efficiency (Lundvall and Johnson, 1994). Several studies have studied this coevolution of production and knowledge of developing countries, and hypothesized that developing countries start from simple assembly, and then move on to gather knowledge through import, imitation, or reverse engineering (Bell and Pavitt, 1993; Kim, 1997; Lee et al., 1988).

Here, the production experience can help a country acquire related knowledge, but the knowledge does not follow straightforwardly. Production helps internalizing tacit knowledge (Nonaka, 1991) but may not lead to knowledge or innovation. The hardware such as equipment can be imported easily, but the disembodied technological elements are much more difficult to be transferred. Of course, to master, adapt, and improve the imported knowledge is even more difficult (Lall, 2000). Therefore, coherent innovation policies, such as educational investment or international technological collaboration, in line with the country's industrial structure are often found in newly industrializing economies (Duysters and Hagedoorn, 2000).

More recent studies revisit the close relationship between production and knowledge, and suggest that the role of production in fostering innovation needs to get more attention (Berger, 2013; Locke and Wellhausen, 2014; Pisano and Shih, 2012). These studies point out the inseparable nature of production and knowledge during stages of production, from developing a prototype to sales. Production capability does not only affect job creation, but it works as a test-bed for innovative ideas until commercialization. This relationship is why many countries are trying to encourage reshoring, and aim for a virtuous cycle of production and innovation even in the era of innovation economy (Locke and Wellhausen, 2014).

T1→P2. Based on the knowledge a country has acquired through production experience, it can utilize this knowledge to advance into new product categories. Diversification is a branching process characterized by incremental accumulation of capabilities (Dosi et al., 2017), since the design capability of countries for new products are based on accumulated know-whys. This type of diversification is more knowledge-based, and a country can acquire international competitiveness in comparatively far products on the product space. In order to do so, a country should first closely study its innovation capability and technological system, in order to distinguish its own competences and explore new fields. After the study, redefining the core products and coherent industrial restructuring can follow afterwards (Ho and Chen, 2018).

Even with the innovation capability and knowledge, it is still difficult for developing countries to benefit from technological advances (Archibugi and Pietrobelli, 2003). Developing countries face challenges to acquire comparative advantage in new products that are less related to their current industrial structure, considering the difference of other production factors such as labor and institutions. Also, it is less evident which products would be promising, especially when the country has to compete with comparatively more developed countries in knowledge-based products.

Therefore, during this stage, a country would go through trials and errors in product diversification. These trials and errors are inevitable processes for advancing into new products, yet should not be avoided considering the positive effects of learning-by-failing (Leoncini, 2016). At this stage, a country cannot replicate other countries' successful cases but try applying its knowledge into products. Therefore, a country should carefully analyze how innovation transforms industries, and "accept the inevitability of change by valuing innovation even above past success (Utterback, 1994)".

2.2.3 Jumps and traps in the diversification process

A country's industry diversification is shown on the product space. Here, what we call as a jump is the diversification that are relatively far from the current capability, which is more unlikely according to the comparative-advantage-following diversification theory. Many previous literatures on international development argue that countries, regions, and cities are more likely to advance to related economic activities that they are already capable of. Yet, countries also deviate from what they have been doing and advance to relatively unrelated activities, and experience a future economic growth (Pinheiro et al., 2018; Saviotti and Frenken, 2008). However, the studies on the unrelated diversification needs more explanations (Ng, 2007), and needs further research on the process and difficulties during unrelated diversification. This study tries to interpret the jumps to new industries less related to the current industrial structure are not mere decisions of a fortunate leader trying to deviate from traditional activities, but rather carefully-designed efforts to expand the business opportunities based on technologies, either imported from foreign countries in the early stage of development or utilizing its accumulated knowledge in the later stage of development.

The first jump on the product space (P0→P1) is the jump without knowledge. The country at P0 lacks a firm knowledge base and its products are focused on raw materials or simple manufacturing. Therefore, it does not have a strong lock-in in their diversification paths, which also means that there are options to diversify into products that seem far from the current capability. A jump from this stage should inevitably rely on foreign knowledge, including both explicit and tacit knowledge. The country would jump to various mid-tech, yet disconnected products and utilize its comparatively advantageous labor resources. The production would be mostly assembly, on capital-intensive or manual-based sectors. From the perspective of global value chain analysis, these activities would be at lower-end of production. This jump needs to solve the information asymmetry and coordination failure that developing countries often face (Lall, 1992; Rodrik, 2009), and therefore government should support the diversification with policies.

The second jump on the product space (P0→P1) is the jump with knowledge. This time, the country utilizes its knowledge and experience accumulated from the past to advance to selected high-tech sectors. It is different from the first jump when the country depended on imported knowledge to enter new industries. During the second jump, the country's knowledge base acquired from production experience is used to explore and advance to possible diversification options. This diversification may seem unrelated on the product space because the diversification is knowledge-based, rather than product-based. Here, diversification options are in knowledge intensive sectors, and countries can participate at higher-end of global value chains.

Table 2-1. Explanations on the two types of jumps

	Jumps without knowledge (P0→P1)	Jumps with knowledge (P1→P2)
Key observation	The emergence of the various mid-tech disconnected products	The emergence of the selected disconnected high-tech sectors
Example	Starting the steel industry in the early 1970s in Korea	Starting bio-similar products by Samsung in the mid of 2000
Source of knowledge	Imported knowledge	Accumulated experience and knowledge
Sectors	Capital intensive and manual based	Knowledge intensive
Global value chain	Low-end	High-end

Whereas jumps tell us the stories of successful unrelated diversification, advancing to comparatively unrelated sectors are not easily achievable. There are studies arguing that branching should be based on the proximity from current capabilities in production (Hidalgo et al., 2007) and knowledge (Boschma et al., 2015). These studies are concerned with the difficulties coming from countries taking too much risk to aim high, and disregarding what they are already doing well. However, these difficulties are not only present during unrelated diversification. Countries advancing through different development stages eventually encounter different traps. Considering that unrelated diversification can be beneficial for economic growth, we need to identify what traps there are during diversification and development processes.

The first trap occurs during the first transition (P0→P1) in failing to challenge the production of core products, located at the center on the product space. In other words, the trap occurs when a country chooses to produce less complex products, with less related knowledge. The core products have more connection – or higher proximity – to other products, whereas peripheral products have fewer connections with other products. Therefore, advancing to production of core products can help the country diversify into more products. If the country cannot start production of core products and stay in products with limited knowledge, it is difficult to diversify in the future, too. Yet, traps are common among less industrialized countries due to the lack of proper infrastructure or complementary intermediate inputs (Lin, 2012). Many countries stay with their current industrial structure or closely follow their factor endowments. Since the lower-income countries are already placed at the periphery of the product space, it is more difficult for them to jump into the core products. As mentioned earlier, the information asymmetry and coordination failure are widespread, and these hinder the firms to challenge producing new products. Information externality discourages entrepreneurs from entering new industries, because the discovery cost of whether the new activities would result in profits is too high (Hausmann and Rodrik, 2003). Coordination failure occur when new industries show scale economies and require close coordination or geographical proximity with related inputs, and government can identify and internalize the coordination externalities to promote new businesses (Rodrik, 2004).

The second trap (P1→T1) is the trap in failing to deepen the core knowledge to support core product. Knowledge internalization and capability building does not occur naturally after production experience, but requires individual and organizational learning (Ernst and Kim, 2002). Considering the dynamic process of knowledge conversion between tacit and explicit knowledge (Nonaka, 1991), the absorptive capacity as defined by Cohen and Levinthal (1990) needs intense effort and commitment to grow. Many countries that are considered as middle-income countries have successfully transformed into countries producing high-tech industries, yet a number of countries stay as subcontractors of developed countries. For example, Thai automobile industry, despite years of production, depends on foreign technologies and production experience has not been converted to knowledge. Large volume of export yet lack of workers with professional education in science and engineering hamper Thailand's further advancement into design, research, and technology development capability (Poapongsakorn and Tangkitvanich, 2001). Accumulation of production experience does not automatically lead to innovation of a country, yet related innovation policies including research and development and education to build local capability should be accompanied.

The third trap (T1→P2) is the trap in failing to diversify into new sector based on the core knowledge. After a country acquired technological capability related to its production sectors, it needs to further diversify its economic structure. A country at T1 still has its comparative advantage in producing products at P1, which mostly are capital-intensive and labor-intensive. These products face stronger competition with other developing countries with higher comparative advantage in labor cost, since the transition from P1 to T1 upgraded the knowledge capability but at the same time weakened the advantage in cheap labor. Therefore, a country stuck at P1 and T1 that cannot advance to P2 eventually faces a slowdown in economic growth. To escape from the third trap, a country needs to challenge new industries based on the accumulated knowledge, and try cross-industry convergence to diversify.

2.3 Linkage and illustration of production and knowledge

Construction of the product space (Hidalgo et al., 2007) and the technology space that some studies call as knowledge space (Boschma et al., 2015) can demonstrate the stories above with datasets, and keep track of evolution stages of production capability and knowledge. Illustration of a product space uses the export data from World Trade Flows data (Feenstra, et al., 2005). The dataset uses the UN Comtrade statistics categorized by the Standard International Trade Classification (SITC) 4-digit based on the origin and destination countries. On the other hand, construction of a knowledge space uses patent data from Organization for Economic Co-operation and Development (OECD) Directorate for Science, Technology and Industry, available at OECD statistics (OECD.Stat). OECD.Stat provides patent data from United States Patent and Trademark Office (USPTO) classified in 4-digit International Patent Classification (IPC). This dataset offers number of patents by country by year based on the inventor's country of residence. Figure 2 illustrates a product space and a technology space in year 2000. Each node on product space represents a product class in SITC 4-digit and each node on technology space represents a technology class in IPC 4-digit.

However, these two spaces use two different datasets of export and patent, and have different units and categories – US dollars by SITC and number of patents by IPC, respectively. Therefore, each space map has different nodes representing different data, and cannot be analyzed on a single space map to give evidence to the relationship between production and innovation.

This study tries to link the product space and the knowledge space on the same space map by utilizing the concordance matrix suggested by Lybbert and Zolas (2014). This concordance matrix utilizes the 'Algorithmic Links with Probabilities' (ALP) approach to mine patent data by using keywords from industry descriptions, and matches the patent categories and product categories using a probabilistic framework. This concordance matrix lets us translate export data on SITC categorization into patent data on IPC categorization, and vice versa. This process gives matching between products and patents at a sufficiently disaggregated level (Dosi et al., 2017), and therefore gives useful information in analyzing the current capabilities of a country in a bilateral perspective of production and innovation capability. **Figure 2-3** shows the product space and converted product space of South Korea in 2000. Each node on product space and converted technology space represents a product class in SITC 4-digit, and each colored note represents a product class with comparative advantage in production or knowledge.

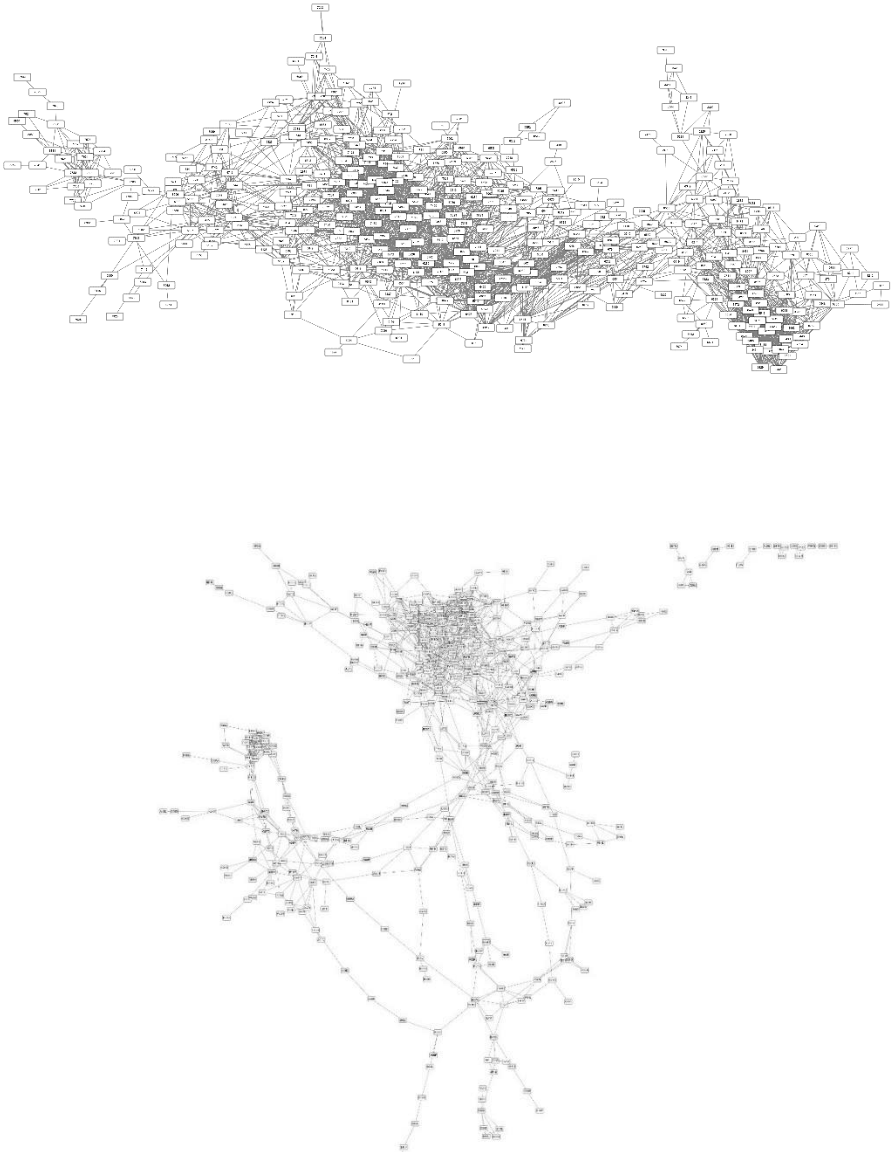


Figure 2-2. Product Space (above) and Technology Space (below) of 2000

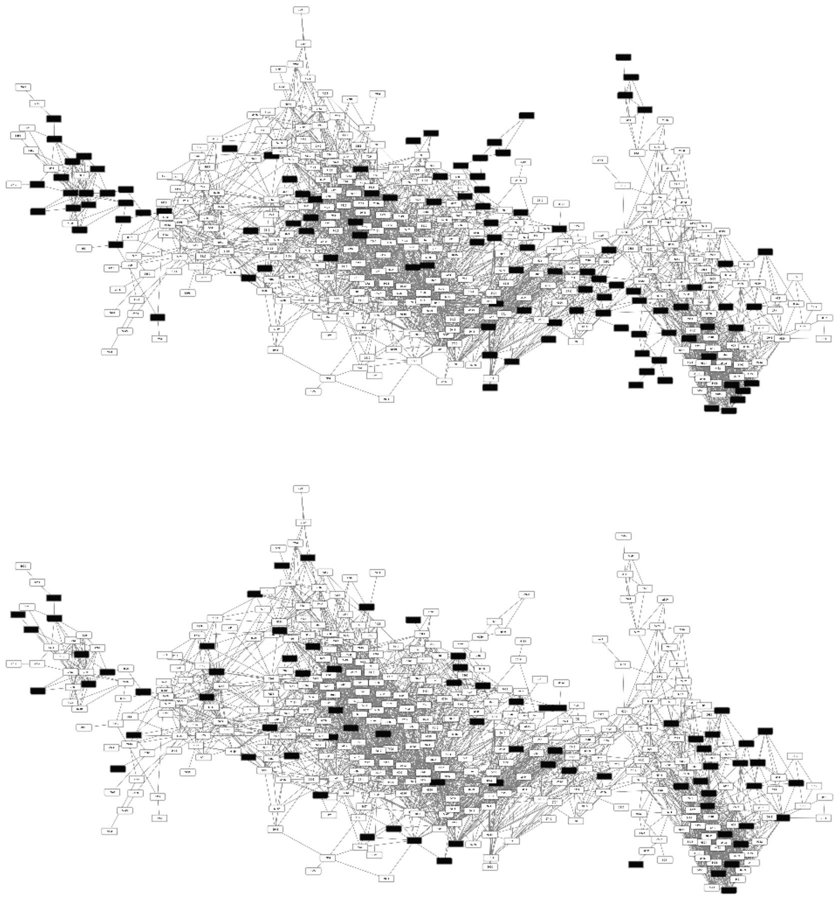


Figure 2-3. Product Space (above) and Converted Product Space (below) of South Korea, 2000

Product space maps by Hidalgo et al. (2007) incorporate technology as one of the factors that decide the proximity between two products. Yet, considering the effects from other factors such as physical factors, infrastructure, or institutions, influence of technological proximity would be moderated. In order to emphasize the role of technology during diversification process, we have distinguished the technology space map from the product space map. In this way, as it can be seen from Figure 3, we can see both production and technological capability of a country, and analyze whether a country that has comparative advantage in production also has comparative advantage in technology.

Differentiating the technological capability from production capability is important in analyzing the diversification path of a country. If a country only has comparative advantage in production, it is hard to say whether the country only has manufacturing capability but no technological capability as a subcontractor, or has innovative capability across the value chain. For example, a country specialized in automobile assembly may have a high volume of automobile export, but as a subcontractor without related knowledge, merely assembling the imported parts. Such simple assembly yet large export volume would not be as helpful in advancing to related products, and therefore obscure comparative-advantage-following diversification process. Paths of the diversification process not only depends on production capability but also on technological capability, and may not occur smoothly following the current comparative advantages. A country's diversification across development stages inevitably includes jumps and traps across the product space and the technology space.

2.4 Revisiting the Korean industrial development process

Most developing countries put efforts to change their economic structure by industrialization, but not all of them succeeded. Some of them only had little progress, and only a few countries could go through diversification and industrialization (Kim, 1999).

Among countries that have experienced successful diversifications, South Korea is a good example for analysis, especially since it has experienced significant economic transitions in the past few decades across various products (Lee & Baek, 2012). This section explains the Korean case of industrial development and diversification, in order to illustrate what kind of jumps and traps occur during development, and how a successful country overcame the difficulties.

2.4.1 Korea from P0 to P1 (1965-1980)

Korea in the 1960s, not so long after the Korean war (1950-1953), was a low-income developing country. It was one of the least developed countries in the world, and Korean GDP per capita was only 8.11 percent of that of the United States in 1965 (Maddison, 1983). Not surprisingly, the industrial structure of Korea was mainly composed of the agricultural products. As in Table 2, Korean top exports by volume were mostly raw materials or agricultural products. Specifically, Korean export depended on raw materials such as iron ore, plywood, and raw silk and aquatic or agricultural products. These products on the product space are placed in the periphery, and do not require complex knowledge or technologies for production. Also, these products do not have many related products or technologies.

However, in 1970s, some changes in the top export products started to appear. Still, simple manufacturing products such as textile products and plywood had the largest portions. Agricultural products and fish were important in export structure, too. However, electronic products emerged as the sixth largest export in 1970, along with steel and metal products. Advancing into these products involves a significant change in industrial structure, which is often referred to as a comparative advantage defying process. It was not an easy decision for the government, and many international organizations such as the International Bank for Reconstruction and Development (IBRD) opposed the government's decision to challenge a different industry from their current industrial structure. A report from IBRD in 1968 claimed that the Korean economy should develop labor-intensive industries first, since entering a technology-intensive sector is too early for Korea (Moon, 2016). Nevertheless, the Korean government emphasized import substitution in technology-intensive sectors such as steel, petrochemicals, fertilizer and cements with large-scale investments (World Bank, 1968). As a result, in 1980, Korean export portfolio included ships in addition to the iron and electronic products, which arise as major exports in the following decades. The industrial transition is apparent if we look at the Korean industry by large sectors as in Figure 4. From 1960s, the number of employed persons of agriculture, forestry and fishing industry has declined whereas those of manufacturing and service industries have increased.

From the technological side, it is evident that this change in industrial structure was not based on the technological capability. Even in 1980 after a significant change in the industrial structure, Korea only had 26 patent grants at USPTO, which was less than 0.1 percent of the total number of patent grants in that year. Korea jumped into core products without knowledge.

Table 2-2. Korean top exports by volume (in SITC-4 digit), 1963-1980

	1963	1970	1980
1	Coated Iron	Plywood	Ships
2	Plywood	Clothing (Fabric)	Footwear
3	Iron Ore	Clothing (Knitted)	Clothing (Underwear)
4	Raw Silk	Clothing (Not Knitted)	Clothing (Outerwear)
5	Clothing	Raw Silk	Clothing (Leather)
6	Non-ferrous Ore	Thermionic Valves and Tubes	Electronic microcircuits
7	Cotton Fabrics	Fish	Iron Tubes and Pipes
8	Vegetables	Non-ferrous Ore	Fish
9	Fish	Cotton Fabrics	Plywood
10	Swine	Footwear	Clothing (Jackets)

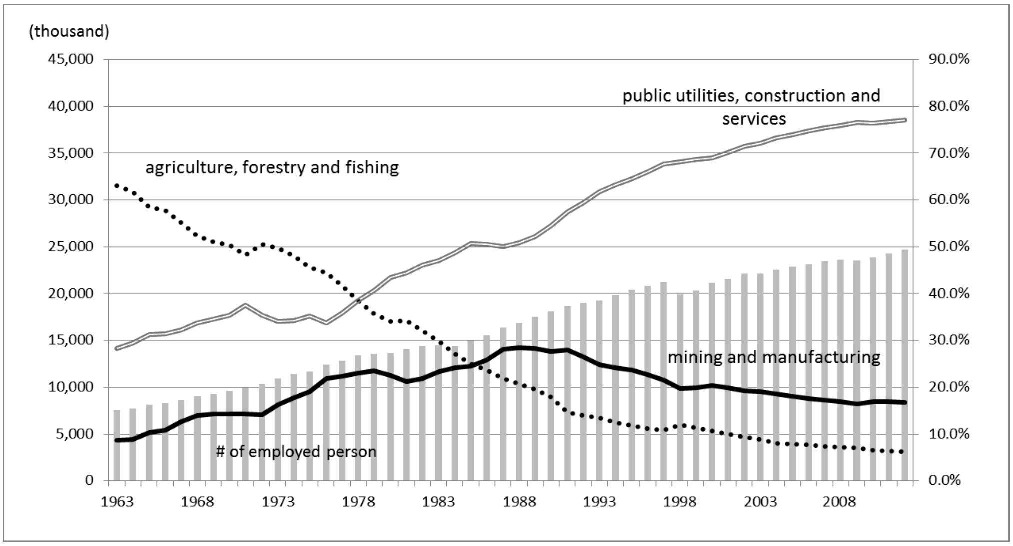


Figure 2-4. Korean industrial portfolio by number of employed person, 1963-2013 (Koo, 2013)

2.4.2 **Korea from P1 to T1 (1985-2000)**

From the 1980s, after several years of production experience in heavy and chemical industry, Korea started to invest on knowledge related with its industrial structure. This was mainly because Korea faced fierce competition from Southeast Asian countries and China, and Korea was losing its cost-competitiveness due to rising factor costs. In order to maintain its industrial competitiveness, Korean companies had to advance into higher-end products or upgrade their products by investing more in technology. Also, because Korea rose as a contender in global market, developed countries were less willing to transfer knowledge to Korean firms (Lim, 1998). As a result, Korea's major knowledge source changed from imported knowledge to accumulated experience and knowledge inside the country. In particular, public and private efforts for research and development led the change. Both R&D investment and number of R&D personnel continued to increase, and subsequently number of domestic and international patents increased. Considering that the persistency in R&D increase is closely related to building technological competence (Kang et al., 2017), this period can be considered as a key period of technology development in Korea.

Let us look at a representative Korean success story from the electronics industry during this period. After a jump to production of electronics in the first stage, Korea moves on to acquire technological capability based on its accumulated experience and efforts to internalize the knowledge (Hobday, 1995; Kim, 1980). Technological capability in electronics in Korea came from its production experience of electronics, not because Korea had enough technological background similar to electronics technology. Successful deepening of knowledge could happen with not only appropriate innovation policies and efforts from private sector, but with years of production. Figure 7 shows an illustration of changes in Korean advantage in the electronics industry. Each node represents a 4-digit product class of electronics industry (SITC 76, 77). Red color shows a comparative advantage in production, and blue color shows a comparative advantage in technology. Compared with 1980 when there was only comparative advantage in production, space maps in 1990 and 2000 show a number of comparative advantage in technology.

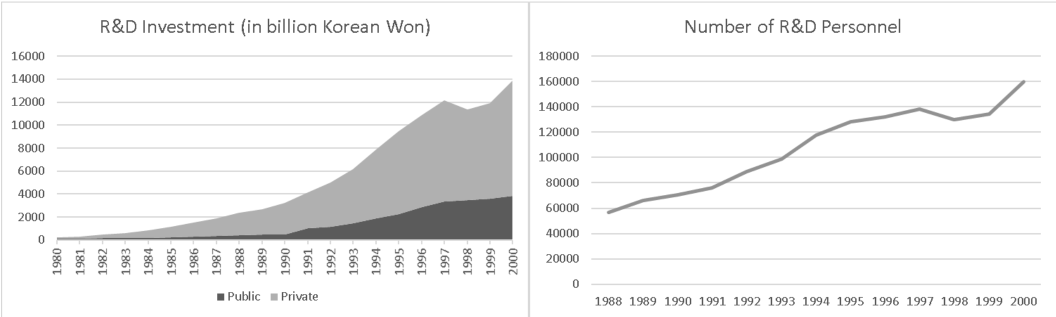


Figure 2-5. R&D investment 1980-2000 (left) and Number of R&D personnel 1988-2000 (right) in Korea

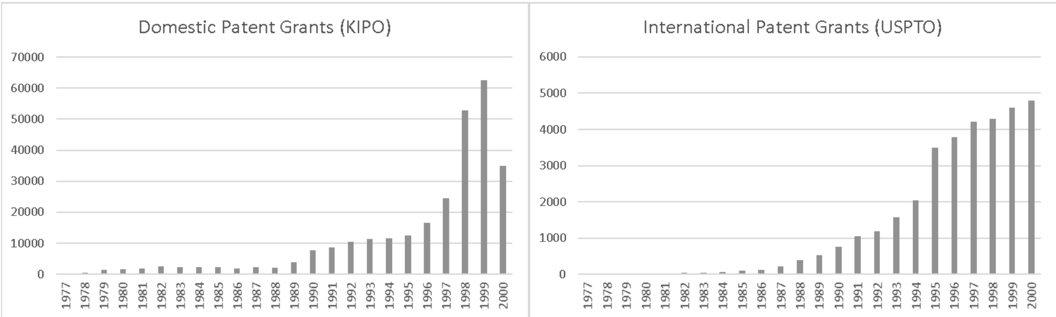


Figure 2-6. Number of domestic patents (left) and international patents (right), 1985-2000

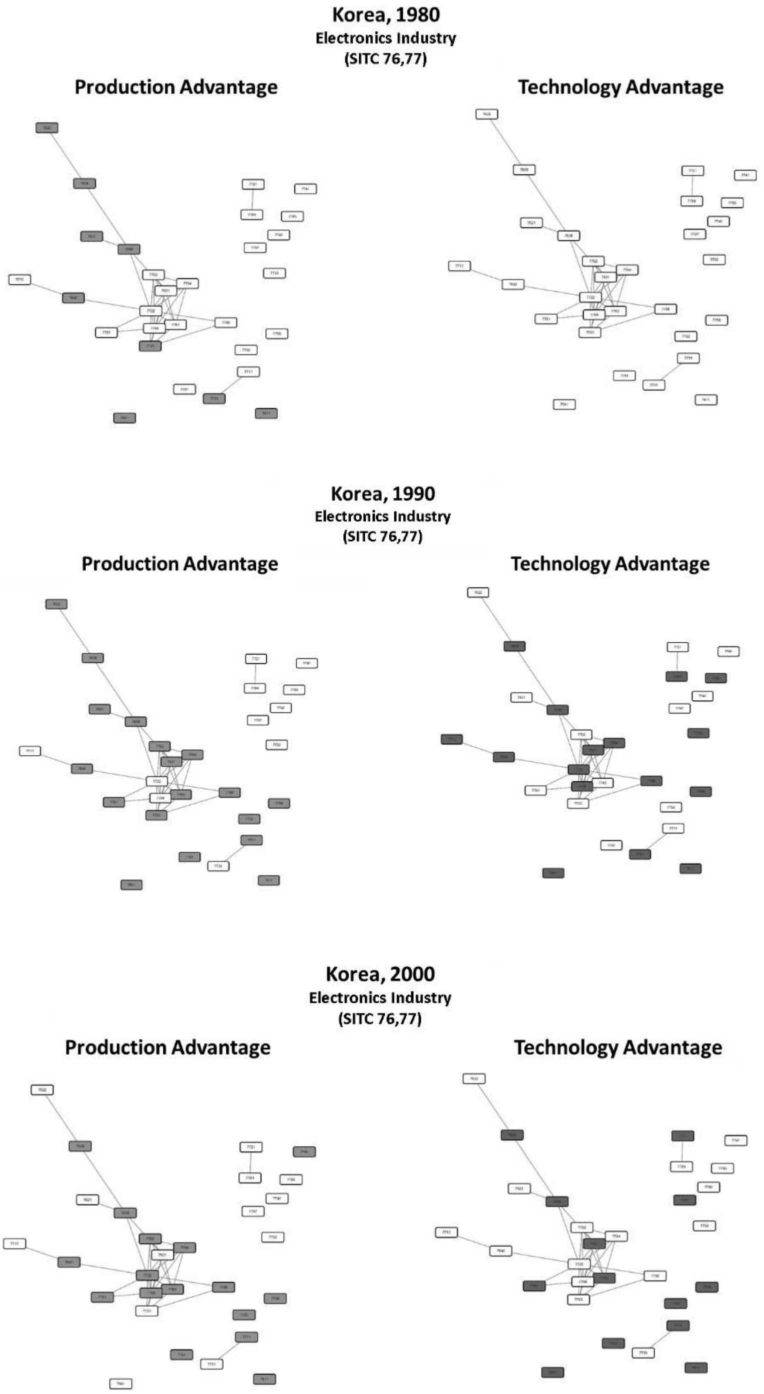


Figure 2-7. Product space and Knowledge space of Korean electronics industry, 1980-2000

2.4.3 Korea from T1 to P2 (2000-)

Until 2000, Korea successfully established production capability and knowledge stock in its key products, namely heavy chemical industries. Since then, however, Korea has been under a trap to generate new sectors (P2) based on the accumulated knowledge (T1).

Unlike Korea in the 1960s and 1970s, the industry portfolio and top export items have not changed in Korea since the 2000s, and industry dynamics has also been unchanged, with the same large companies occupying the top sales. In this period, growth of information and communication industries was noticeable, with strong promotion of technology-based small and medium enterprises (Yeon et al., 2016). However, the industrial structure did not experience much change, and still most of the exported products and largest companies remain unchanged in 2000s, despite the government's effort as an organizer and manager in knowledge networks for emerging industries (Choi & Park, 2018). Facing continued competition with China and countries in developing parts of the world, the Korean government is trying to transform its industrial structure into more digitalized products, but some initiatives lack detailed and workable implementation steps (Sung, 2018).

Table 2-3. Korean top exports by volume (in SITC-4 digit), 2000 and 2010

Rank	2000	2010
1	Electronic Microcircuits	Electronic Microcircuits
2	Automobile	Ships
3	Computer Parts	Automobile
4	Ships	Display
5	TV and Radio Transmitters	Automobile Parts
6	Data Processor Parts	Telecom Parts
7	Synthetic Fabrics	TV and Radio Transmitters
8	Telecom Parts	Computer Parts
9	Electronic Valves and Tubes	Cyclic Hydrocarbons
10	Data Processor Parts	Machinery

Table 2-4. Largest companies of South Korea, 2000 and 2010 (Korea Economic Research Institute, 2015)

Rank	2000	2010
1	Samsung	Samsung
2	Hyundai	Hyundai-KIA Motors
3	LG	SK
4	SK	LG
5	Hyundai Motors	Lotte
6	Hanjin	POSCO
7	POSCO	Hyundai Heavy Industries
8	Lotte	GS
9	Kumho	Hanjin
10	Hanhwa	Hanhwa

2.5 Discussion

Based on the reflection of the Korean case study of economic development and jumps, this chapter suggests that countries need different policies for each stage of development to the countries are at different stages of development and specialized in different sectors on the product space map, The policy recommendations aim to provide specific policy directions to countries trying to advance into less related industries, or jumps, based on different production experience and technological capabilities. Based on the reflection of the Korean case study of economic development and jumps, this study suggests that countries need different policies for each stage of development to the countries are at different stages of development and specialized in different sectors on the product space map, The policy recommendations aim to provide specific policy directions to countries trying to advance into less related industries, or jumps, based on different production experience and technological capabilities.

Firstly, in the early stage of development, a country should not solely depend on comparative advantage following products, but challenge the production of 'core products' with imported technology. It is very rare that a country at this stage possesses experience and capability in producing the core products, and previous studies on path-dependence argue that these countries should specialize on simpler products that the country has been producing. However, considering the long-term opportunity to acquire core knowledge from producing core products, government policies should support and encourage entrepreneurs to challenge distant products from current capabilities. Without policy supports, information externalities and coordination externalities would be too high for private sectors to explore and advance into new and far products.

Secondly, after securing the production capability in core products, a country needs to deepen the ‘core knowledge’ with own innovation effort. Societies at different stages have different capabilities to learn and internalize the knowledge. Countries can learn by doing, or producing, but there should be efforts to learn, too (Archibugi and Pietrobelli, 2003). After industrialization from the first stage, competitiveness of countries comes from deciding what technological capabilities or skills are possible and beneficial to learn (Amsden, 1989), and governmental efforts to foster absorptive capacity are crucial. Also, mentioned, countries would need to build a virtuous cycle that provides more opportunities for learning and simultaneously improves the learning ability (Kim and Heshmati, 2013; Stiglitz and Greenwald, 2014)

Thirdly, at mature stage, a country needs to diversify into the ‘new core products’ based on the accumulated knowledge base. The country would try to diversify further from products in P1, since products in P1 would face fierce competition from other developing countries who are following similar patterns of development. Here, successful diversification through introduction of new products crucially depend upon the existing stock of knowledge (Dosi et al., 2017). Therefore, promotion policies on educational-industrial cooperation, and patient capitals for new products at early-stage would be helpful at this stage.

The findings and implications call for further research. This chapter dealt with the national level development stages, but studies on different levels would lead to further implications, especially under recent open markets. Firms also diversify and grow through coevolution of production and knowledge, and the patterns and speed of diversification would differ by industrial sectors. Additional analysis on sectoral-level or firm-level diversification cases would generalize our results and provide further practical policy implications on industrial development of developing countries.

There is a limitation coming from the dataset, since this study used the export and USPTO patent data. Export data cannot represent the domestic production and consumption, and it is probable that the production capability of developing countries are more closely related with domestic production and consumption than exports. Also, national patent data could be as valuable as the international patent data, especially when the country is still developing its knowledge base. Therefore, future studies using country-specific cases and domestic production or patent data would enrich the country-specific policy implications from this study.

2.6 Conclusion

This chapter suggested the three stages of industrial development, across the product space and technology space that show production capability and technological capability of a country, respectively. The three stages include challenging production of the core products, accumulation of knowledge from the production experience, and product diversification based on the knowledge gained. Although previous studies argue that path-dependent is predominant during industrial diversification and development, this study suggests that the jumps and traps rather than a smooth and gradual development characterize the product diversification process. In particular, the co-evolutionary development process between production and knowledge can explain the jumps and traps of the diversification process. The findings contribute to the understanding of co-evolutionary development paths of developing countries, and highlight on the different strategies at each stage.

Chapter 3. Role of production in fostering innovation

3.1 Introduction

This chapter aims to find the empirical evidence between the production and innovation, and more specifically how current production capability influences future development of innovation capability. This approach not only re-emphasizes the role of production on fostering innovation, but also adds multilateral perspective on the discussion of heritage theory on capability development. This chapter studies the link between production capability represented by production advantage and innovation capability represented by technological advantage, based on the path-dependence theory with the product space mechanism (Hidalgo et al., 2007). Though the methodology has been suggested relatively recently, there have been a number of studies adopting the concept of product space to knowledge evolution and capability development in region or national level (Neffke et al. 2011; Boschma et al. 2013; Essletzbichler, 2015). Nevertheless, these studies on knowledge diffusion using the product space methodology assume the emergence of new industries as knowledge development, and do not take into account of the technological factors pointed out in Boschma et al. (2015) and Colombelli et al. (2014). They explore the path-dependence theory from the perspective of production only or technology only. Despite the efforts from previous literatures on innovation that consider production capability as a key component of innovation capability, they lack empirical and numerical evidence to identify the link between production and innovation.

Evolutionary studies provide theoretical frameworks to consider innovation as a cumulative process of searching for a small advance based on its experience or routines (Nelson and Winter, 1982). It is the result of exploration and ways for small advances, or in other words "navigating through a rugged landscape, rather than climbing up the ladder" as Hidalgo and Hausmann (2007) more recently described. It is not a simple and direct result of combination or production of knowledge, but involves additional steps such as transformation of new knowledge into artifacts and continuous adjustments to these artifacts based on the response to the market (Bathelt et al., 2011). Innovation is a result of such numerous small steps in the past, and these steps involve inevitable learning-by-failing (Leoncini, 2016) that raw ideas go through before commercialization. Trials during production steps leading to competencies take place before the ideas become tangible outputs over years of experimentation (Archibugi, 2017), and production capability enables these trials for innovation. In addition, since technological knowledge is not only shaped by the existing knowledge structure but also the ways in which knowledge can be commercialized, and delivered to customers (Pisano and Shih, 2012), technological development should be studied also along with production capability.

Although the definition of capability differs by scholars, this study defines production and technological capability as comparative advantage in products and technologies as described in Section 4. More specifically, experience of technological capability refers to technological advantage in the past, and development of new technological capability refers to emergence of technological advantage in a technology that a country did not have advantage in the past. The same definitions apply for terms on production, too. Based on the export and patent data from 92 countries from 1980 to 2005, this study investigates whether countries with production advantage in certain products are more likely to develop technology advantage in nearby products. Results of statistical and econometric analyses support the hypothesis that having comparative advantage in production has positive influence on development of technological capability. This relationship between production and innovation is positive even after controlling the distance between technologies for similar products and technologies that are closely located with each other in the space map.

The rest of this chapter is aligned as follows. Section 2 sets out the theoretical discussions on the relationship between production and innovation, along with the key ideas from studies on product space and technology space. Section 3 delineates the data, and Section 4 describes the methodology. Section 5 presents the descriptive statistics and econometric estimation. Section 6 discusses implications for theory and practice, with limitations and possible future research. Finally, Section 7 ends the chapter with the conclusion.

3.2 Previous Studies

3.2.1 Discussion on relationship between production and innovation

Until recently, many innovation studies have considered research and development to be one of the most important factors in knowledge generation (Mansfield, 1965; Pakes and Griliches, 1980; Love and Roper, 1999; Mairesse and Mohnen, 2005; Lerner and Hall, 2010). These studies emphasize the positive role of research and development in national or firm level innovation, and many policies aiming to foster innovation focus on financial, educational, and legal supports towards R&D. Such discussions on innovation regard the manufacturing capability as merely one of the dimensions of innovation capability (Binz and Truffer, 2017; Guan and Ma, 2003) or a separate capability from innovation capability (Sturgeon, 1997).

However, recent studies express suggest that the role of production in innovation has been overlooked. From 2010, the MIT Production in the Innovation Economy (PIE) Commission has emphasized the importance of production capability in creating jobs, and maintaining and advancing the innovation capability. In *Making in America* (Berger, 2013), the PIE Commission expands the argument to include innovation from production. Emphasis on innovation is the main difference from the previous publication *Made in America* (Dertouzos et al., 1989) which analyzed the role of production in economic growth and job creation. Key argument of Berger (2013) is that production capacity and experience helps the nation to improve productivity and develop new ideas in products, services, and business models. This is due to the inseparable nature of production and innovation. Production and innovation are inseparable because innovation occurs during stages of production such as testing of prototypes, optimization of production system, or interaction with customers after the tangible products come out. Pisano and Shih (2012) supports this argument and underlines the necessity to co-locate R&D and production to encourage interaction between producers and designers. They argue that it is necessary to keep the research facilities near factories, to test new ideas and make small improvements before finally reaching an innovative outcome. The authors refute the premise that considers manufacturing and production stages as low value-added, simple tasks that are separable and distant from R&D and innovation. These studies suggest that innovation policies need to clearly recognize the close relationship between production and innovation.

Hence, it is possible to add useful discussion on emergence of new technologies at national level by involving the effect of production capability of countries on technological capability, and including the possibility of innovations stemming from accumulated production routines for a long period. Yet, even the previous studies acknowledging the relationship between production and innovation either do not provide empirical evidence, or rely heavily on case studies in a limited number of sectors or countries with limited policy implication on national-level innovation policies. Therefore, it is important to identify and test the relationship between production and innovation through a cross-country study.

3.2.2 Path-Dependence characteristic of capability evolution through network analysis

Following network-based concepts to plot products on a space map, Hidalgo et al. (2007) suggested product space which uniquely contributed in visualizing development paths and countries and evolution of industries. The authors compare the countries to monkeys and products to trees, and describe the development process of countries as monkeys jumping across trees to advance to richer part of the forest. In this metaphor, the authors assume that countries' production capabilities advance to similar products in which the countries already have advantages in exporting. Hausmann and Klinger (2007) also suggest the concept of product space based on current capabilities represented by the export structures, without using network analysis.

Both Hidalgo et al. (2007) and Hausmann and Klinger (2007) argue that countries advance to nearby products, and that the initial pattern of industrial specialization influences future industrial structural transformation. At the regional level, Boschma et al. (2013) and Neffke et al. (2011) reach the same conclusion that a region is more likely to diversify into new industries that are closely connected with the existing industrial structure. This argument is against the traditional theory of Heckscher-Ohlin model, which argues that countries specialize based on their relative factor endowments under the assumption of free trade. Whereas several national-level economic studies including Aghion and Howitt (1992) assume homogeneity across products, product space theory presents different paths of products through which countries can advance. This is in line with

Hausmann et al. (2007) who argue that the export structure of a country is critical to the development of its economy: countries that produce goods typically produced in rich countries are likely to become richer in the future, whereas countries that produce goods typically produced in poor countries are likely to remain poor. Hidalgo and Hausmann (2009) develops quantified methodology to measure economic complexity that represents the economic structure. The authors propose that the future economic growth can be predicted by the deviation of a country's actual level of income from expected level of income based on economic complexity. A recent study by Hartmann et al. (2017) confirms the close relationship between export complexity and economic development of a country, and argues that export complexity even influences the level of income inequality.

Bahar et al. (2014) study the possibility of knowledge diffusion across geographically neighboring regions by looking at similar diversification patterns of industry emergence in 123 countries. Their findings suggest that a country is more likely to add a new product to its export basket if its neighboring country is already exporting that product. Furthermore, growth of export volume is higher if there is a neighboring country that produces it. On the other hand, in their study of 50 Spanish regions, Boschma et al. (2013) show that in regional level, emergence of new industries in regions depends more on proximity to the existing regional industrial structure than to the national industrial structure. These studies provide evidence to the path-dependence theory that previous production capability matters in emergence of new industry at smaller regional levels or at larger multinational levels. These findings are in line in with previous discussions on product space or evolutionary economic theories, in that new capabilities or diversification decisions are built upon routines.

Product space can also be helpful in summarizing the production structure and studying comparative advantage of a specific country. Felipe et al. (2012) list the products and countries with highest and lowest complexity, and concludes that major exporting countries of more complex products (i.e. machinery, chemicals) are high-income countries (i.e. Japan, Germany), and major exporting countries of less complex products such as raw materials are low-income countries (i.e. Cambodia, Papua New Guinea). Ferrarini and Scaramozzino (2015) use product spaces of the United States and China to compare their trade profiles, and visualize which sectors the two countries occupy. In addition to current analysis, some studies use the product space to analyze the different growth patterns or future development paths. Romero et al. (2015) point out different product specialization result in different economic growth patterns, and argue that specialization in highly sophisticated products enabled South Korea to grow faster than Brazil from 1960s to 2000s. On the other hand, Brady, Doyle, and Noonan (2013) study information and communication technology industries to anticipate the export potential through measuring current production capabilities in Ireland and Finland.

Yet the previous studies using product space have limitations in that they consider innovation as production and export in a new product. Several studies point out that there is a significant difference between production capability (know-how) and technological capability (know-why), and it is necessary to distinguish the two different types of knowledge (Lall, 2000; Lundvall and Johnson, 1994). Also, there should be an additional distinction between production with technological capability and production without technological capability (Neffke et al., 2011), but analyses using only export data cannot show this distinction. Advance in production capability and advance in technological capability are not identical in terms of innovations, and there should be an effort to discover the linkage between them during stages of capability emergence and development.

On the other hand, several researchers suggest the concept of technology space or knowledge space, using the methodology to build product space based on the patent data to map the relatedness among knowledge. Especially, researchers from the field of evolutionary economic geography use the technology space to analyze the patterns of capability development and knowledge evolution. Evolutionary economic geography adopts the evolutionary economics argument that economic individuals act based on their routines that are accumulated over time (Nelson and Winter, 1982). It also takes a dynamic perspective on studying birth and deaths of companies or industries, and studies spatial evolution of sectors and regions (Boschma and Frenken, 2006).

Although geographical factors are not considered as variables in this chapter, studies from evolutionary economic geography offer a good reference to build up a network space based on technological measures. Recent evolutionary economic geography literature on regional diversification also consider relatedness as a key factor of diversification (Boschma and Capone, 2015; Boschma et al., 2017; Tanner, 2016). Based on the product space methodology on regional production (Boschma et al., 2013) Boschma et al. (2015) develops a discussion on technological evolution by building up a technology space based on patent data of 366 US cities. Their findings suggest that the entry probability increases and exit probability decreases if a technology is more closely related with existing knowledge structure. This result from technology space is in line with the findings of product space studies suggesting the path-dependence of capability evolution. Using the same approach, Colombelli et al. (2014) analyzed the technological evolution of European countries with the same conclusion that previous knowledge structure is closely linked with future emergence of new technology. The authors put special attention on technological advance in newly emerging sector of nanotechnology, and argue that path-dependence is also applicable in explaining innovation dynamics of technology-based industry. Some studies also add to the discussion on path-dependence of innovation by providing evidence on clustering of patents across technology classes (Kogler et al., 2016; Kogler et al., 2013), showing that high technological relatedness has a positive effect on the entry probability of a technology. These studies on technology space consistently argue that knowledge follows path-dependence and evolves towards related technologies, similar to the pattern of production capability evolution advancing to similar products. Therefore, regions are encouraged to support technological specialization in related technologies that are more developed yet nearby to what the countries already have advantage in (Balland and Rigby, 2017).

Previous studies on technology space provide evidence to support the path-dependence theory of knowledge development, yet again have the limitation in overlooking the production capability in knowledge evolution. Technological capability and knowledge often stay in the tacit form (Nelson and Winter, 1982; Nonaka, 2007) and therefore are even more difficult to spread, evolve, or be transmitted, often referred to as characteristics of sticky information (von Hippel, 1994). Also, as Minondo (2011) points out that export diversification is not an automatic result of economic development, technological diversification is not a corollary of economic development.

Knowledge itself does not automatically lead to innovation, but trials and errors from production based on existing knowledge can spur innovation. Therefore, considering the close relationship between production and innovation, interlinking production and technology on a single space would complement the previous studies. In this way, it is possible to add a multilateral perspective on path-dependence theory, and invite attention on the overlooked role of production in fostering innovation.

3.3 Data

This research utilized two types of datasets – export and patent – for measurements of production and innovation capability respectively. There are pros and cons for both export and patent data, but both data hold useful numerical information especially for empirical studies. First, using export data as a measure for production capability may not reflect every part of national production capability since a significant amount of production is for domestic purposes, and export volume does not reflect the exact value-added resulting from the export. However, considering that export data can help revealing in which product level the country is able to appeal and sell its own products to other countries, export volume can be used as proxy measure for capability to produce competent products at international standards. Therefore, following previous studies that present export performance as a proxy for production capability at national level (Kim et al. 1987; Shin, 1996; Hausmann et al., 2007; Hausmann and Klinger, 2007), this study uses export data to calculate comparative advantage in production.

The export data in this study primarily uses the World Trade Flows data (Feenstra et al., 2005) for 1962-2000. This dataset is based on the UN Comtrade statistics at the Standard International Trade Classification (SITC) 4-digit level, and includes import and export data sorted by country of origin and destination. However, since the dataset does not cover year 2001 and after, dataset for 2001-2010 is constructed based on UN Comtrade data at the SITC 4-digit level. SITC has four revision types with the most recent revision of Revision 4 updated in 2006, and Revision 3 in 1986. More recent revisions may have their advantages in classifying recent international merchandises, acknowledging that traded items become more specified or obsolete as years pass by. However, in order to keep the consistency of the analysis, this study uses SITC Revision 2 that can be applied throughout the timespan for the export data since the constructed dataset includes data before Revision 3.

Also, there are certain limitations of patents to reflect the country-level technological capacity because patent data do not fully reflect the overall society's inventive activities or knowledge (Pavitt, 1985). There are differences among industries or inventors in the propensity to patent, and inventions may not always result in patents. Also, a raw tally of number of patents does not distinguish between more and less valuable patents, and may require further information such as citation to assess the value of each patent. However, patents are legal documents that contain detailed records and grant certain authorities, and the information in patents is highly precise and accurate (Joo and Kim, 2010). The patent statistics can provide ample evidence on evolutionary processes of technology and knowledge with numerical information which can reflect the inventive performance of countries or individuals. Patents are also useful in keeping track of international diffusion and convergence of knowledge (Caviggioli, 2016) and development of industries and knowledge structure. Therefore, patents are often used as proxy measurements for innovative activities of a country in many previous researches studying knowledge and innovation including Jaffe and Trajtenberg (2002), because they have a close link to invention, cover a wide range of technologies and provide ample source of information. Acknowledging the fact that patent data may not encompass every advance in knowledge, this study uses patent data as an indicator to measure a country's technological capability.

This study measures the country-level technological capability based on the patent statistics developed by Organization for Economic Co-operation and Development (OECD) Directorate for Science, Technology and Industry, available at OECD statistics (OECD.Stat). OECD.Stat offers United States Patent and Trademark Office (USPTO) and European Patent Office (EPO) applied and granted patent data by technology by country, and by inventor's country of residence and applicant's country of residence. This study uses the number of granted patents under USPTO, from 1980 through 2005. Each patent data is classified by 4-digit International Patent Classification (IPC), and numbers may not be in integers because a patent may have multiple co-applicants from different countries or have multiple subclasses.

The entire dataset includes 93 countries with available datasets, from both OECD patent statistics and World Trade Flows data and UN Comtrade export datasets. The 93 countries are the countries that meet the following criteria for export and patent statistics. The export dataset, following Hausmann et al. (2011), only includes the countries with population above 1.2 million US dollars at 2000 and net export above 1 billion US dollars at 2000, because the export data from countries that are too small in either population or trade does not show the whole picture of their economic structures. For patents, the dataset excludes countries with number of patents below 10 at year 2000 to prevent misrepresentation during calculation of technological comparative advantage.

Linking the product space and technology space requires a way to translate the export data into patent data or vice versa. There have been several attempts to provide a linkage between production and innovation datasets, namely Yale Technology Concordance (YTC) and WIPO technology concordance table. Among several options, this study adopts Algorithmic Links with Probabilities (ALP) concordance that provides crosswalks between classification of industry including SITC, ISIC, NAICS, and classification of patents of IPC (Lybbert and Zolas, 2014). ALP concordance is structured based data mining, with more than 2 million patent records from PATSTAT database. It covers both ways for linkage of both industries and technologies with different weights, and therefore one crosswalk cannot be applied backwards but provides a more reliable correspondence. ALP enables the transform of IPC 4-digit patent data classified under SITC 4-digit, revision 2, and makes it possible to reflect technological capabilities on the product space. The number of SITC 4-digit subclasses differ by year, yet the dataset covers 785 subclasses for exports identified in the ALP concordance for consistency.

In some estimations, it is necessary to group countries based on their manufacturing ratio to merchandise exports. Since this study uses exports as primary dataset, manufacturing ratio to merchandise exports rather than national income level would better represent each group’s industrial characteristics and provide robustness. The data comes from World Development Indicators provided by the World Bank. This study uses the average manufacturing ratio from 1980 to 2005, and divides the countries in three groups. Countries are classified as having high manufacturing ratio if the ratio is higher than 70 percent, middle manufacturing ratio if the ratio is between 30 and 70 percent, and low manufacturing ratio if the ratio is lower than 30 percent. Following this classification, there are 27 countries with high ratio, 31 countries with middle ratio, and 24 countries with low ratio.

3.4 Model

In order to keep track of the evolution paths of production or technologies of countries, it is essential to draw the relatedness among the products or technologies. Measuring the relatedness between products or technologies is not novel. Starting from Jaffe (1986) illustrating the concept of technological proximity that further leads to the concept of technology space, there have been a series of other studies on technological proximity (Aharonson and Schilling, 2016; Joo and Kim, 2010; Stellner, 2014; Yan and Luo, 2015). Among these, this study adopts the methodology that measures bipartite proximity between two products or technologies based on the likeliness of a country to have advantages in both (Hidalgo et al., 2007; Hidalgo and Hausmann, 2009; Boschma et al., 2013). If two products are likely to be co-exported in countries, then the two products are considered to be closely related to each other.

Product space can map every product in a single space, and it is especially useful to present a country's advantages with its current capability. It shows a country-level structure of output rather than aggregate output, which gives a critical insight on what the country produces and how competent the products are in the global market (Hausmann and Hidalgo, 2010). In order to plot and link the products represented by single nodes on the network space, it is necessary to calculate the relatedness, or distance between the products. It is possible to create a technology space based on the patent database using the same framework of product space. Similar with product space, each node of the technology space represents a technology category – in this study, 4-digit USPTO patent class – and each link indicates the relatedness between two technologies. Constructing a technology space can be helpful in drawing the positions of core and peripheral technologies according to relatedness with other technologies, and provides evidence to knowledge evolution paths of countries. Instead of drawing separate product space and technology space, this study tries to translate production data into technology-level. By doing so, it is possible to see in which technologies a country possesses advantage in production, technology, or both on the same technology space map.

The key measurement in this analysis tries to figure out how much production or technological capability of a country exists around a particular product. Among a number of choices to measure the capability, this study adopts the classic concept of revealed comparative advantage comparative advantage (RCA) from Balassa (1965). RCA measures whether export share of a particular product of a country is larger than that of the world. Therefore, if the ratio of export share of a country of a product to export share of the world of a product is equal or larger than 1, then the country is considered as having a comparative advantage in that product. If the value is less than 1, the country does not possess comparative advantage in that product. When measuring technological capability, a number of previous studies used revealed technology advantage (RTA) that observes technological strengths of a country, using the same logic as in RCA (Soete, 1987). Whereas RCA uses product categories for classification, RTA uses patent categories. Each RCA and RTA are defined as:

$$RCA_{c,p} = \frac{x(c,p)}{\sum_p x(c,p)} \Bigg/ \frac{\sum_c x(c,p)}{\sum_{c,p} x(c,p)}$$

$$RTA_{c,t} = \frac{x(c,i)}{\sum_i x(c,i)} \Bigg/ \frac{\sum_c x(c,i)}{\sum_{c,i} x(c,i)} \quad \cdots\cdots \text{(3-1)}$$

where c stands for country, p stands for product(SITC4), i stands for technology(IPC), and x for value of export volume or number of patents.

In product space, based on RCA, it is possible to calculate the conditional probability of whether country c that produces product p_1 would be likely to produce product p_2 also ($\mathrm{P}\left(\mathrm{RCA}x_{p_1} \geq 1 \middle| \mathrm{RCA}x_{p_2} \geq 1\right)$), and vice versa ($\mathrm{P}\left(\mathrm{RCA}x_{p_2} \geq 1 \middle| \mathrm{RCA}x_{p_1} \geq 1\right)$). This means that for every pair of products, there are two conditional probabilities. Proximity between products p_1 and p_2 can be defined as the minimum of the pairwise conditional probability of countries that export p_1 and p_2, and the same methodology can be used to measure the proximity between two technologies. Proximity φ_{p_1,p_2} between products p_1 and p_2 is defined as follows:

$$\varphi_{p_1,p_2} = \min\{\mathrm{P}\left(\mathrm{RCA}x_{p_1} \geq 1 \middle| \mathrm{RCA}x_{p_2} \geq 1\right), \mathrm{P}\left(\mathrm{RCA}x_{p_2} \geq 1 \middle| \mathrm{RCA}x_{p_1} \geq 1\right)\} \quad \cdots\cdots \text{(3-2)}$$

The proximity between products show which products are closely related with each other, and structure a matrix of 775*775 to list every proximity among the 775 products. This matrix reveals which products of a country have many related products with high proximity. Hidalgo et al. (2007) call this concept of high relatedness with other products as ‘density’, and country-specific, product-specific density can be calculated based on the proximity between products. Density can be easily understood as the concept of average proximity, which is the sum of proximities between a particular product and products with RCA, divided by the sum of all proximities linked to that product. ω_{p_2}, density around product p_2, is defined as follows:

$$\omega_{p_2} = \sum_{p_1} x_{p_1} \phi_{p_1,p_2} / \sum_{p_1} \phi_{p_1,p_2} \quad \text{(3-3)}$$

Following Hidalgo et al. (2007), Boschma et al. (2013), and Colombelli et al. (2014), this study assumes that five-year time lag is appropriate to measure the impact of previous economic structure to influence emergence of innovations. Therefore, this analysis divides the time period from 1980 to 2005 by time periods of 5 years, with years 1979 and 2006 also included for the purpose of calculating 3-year average for year 1980 and 2005 respectively.

However, since the relatedness between products and technologies vary as the time changes (Joo & Kim, 2010), this study calculates each 5-year intervals’ proximity and density for products and technologies for. In addition, in order to avoid fluctuations coming from year-specific characteristics, the analysis uses the average of 3 years instead of a single year (e.g. average data of 1979 through 1981 instead of the data of 1980 only) for analysis. Using average for a certain period is more useful in avoiding year-specific fluctuation for patent data, because USPTO patent applications take 18 months until publication, and innovation capability reflected by number of patent granted is a continuous result from a certain period of trial and errors.

This study aims to estimate how production capability in related technologies influences future technological capability. Therefore, the analysis regresses the technological capability at time $t+5$ against production density at time t. The econometric estimation can be written as follows:

$$RTA_{c,i,t+5} = \beta_1 RTA_{c,i,t} + \beta_2 ProdDensity_{c,i,t} + \Phi_c + \psi_i + \alpha_t + \varepsilon_{c,i,t} \cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(3-4)}$$

where the dependent variable $RTA_{c,i,t+5}$ is 1 if the country c has technological advantage in technology i at time $t+5$, and 0 if otherwise. Also in the independent variable $RTA_{c,i,t}$ is 1 if the country c has technological advantage in technology i at time t, and 0 if otherwise. $ProdDensity_{c,i,t}$ measures the density of production capability of country c around technology i at time t. The estimation also includes Φ_c as country-fixed effect, ψ_i as technology-fixed effect, α_t as time-fixed effect, and the error term $\varepsilon_{c,i,t}$.

This estimation focuses on explanatory power of the key independent variable $ProdDensity_{ic,,t}$. This study investigates the effect of production capability on the future technology capability, and expects the estimation to be $\beta_1 \neq 0$ and $\beta_2 \neq 0$, incorporating the path-dependence of technological capability evolution. More specifically, the accumulated experience of production is expected to have favorable influence on the technological capability in the future, so the result of $\beta_2 > 0$ will support the hypothesis.

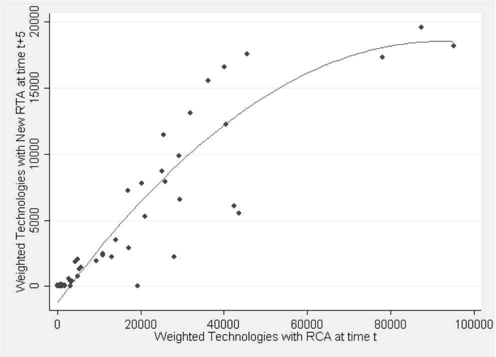
The estimation of the equation is based on a linear Ordinary Least Squares (OLS) model, yet the equation is tested with other methods in order to ensure the consistency. Because the dependent variable is not continuous but binary with 0 or 1, using a linear estimation may involve inefficiency since the error term does not follow normal distribution, and there is no guarantee that the estimator will be between 0 and 1. Therefore, this study tests this binomial dataset with Generalized Linear Model (GLM) as in Colombelli et al. (2014) along with probit model (Neffke et al., 2011) and seek to improve the efficiency of estimation.

3.5 Empirical Results

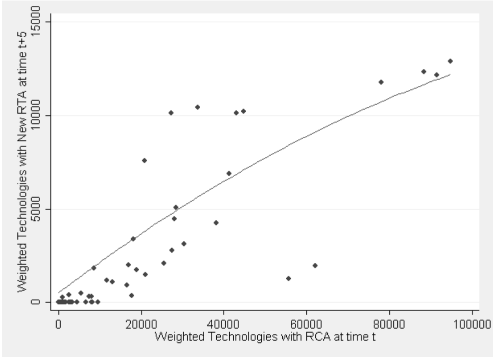
This study provides both statistical and econometrical evidence in testing the role of production experience in future development of technological capabilities. Here, the development of technological capability is analogous to acquiring technological comparative advantage. Based on the patent data, a country has a comparative advantage in technology if $\mathrm{RTA} \geq 1$, and has newly developed technological capability if $\mathrm{RTA} < 1$ in the previous period and achieved $\mathrm{RTA} \geq 1$ in the next period. The time periods are divided into 5-year periods following previous studies on capability development (Boschma et al., 2015, 2013; Colombelli et al., 2014), assuming that five years are long enough to provide evidence on emergence of industry and following technology emergence. Base years as time t are 1980, 1985, 1990, 1995, and 2000 and comparison years as time t+5 are 1985, 1990, 1995, 2000, and 2005, respectively, for comparing technological emergence.

First, for the statistical analysis, **Figure 3-1** shows the relationship between weighted number of technologies with RCA larger than 1 at time t and weighted number of new technologies with RTA larger than 1 at time $t + 5$ from 1980 to 2005. Each technology has been weighted by the sum of proximities around the technology, in order to make differentiation among different classes of technologies and not consider each technology as identical. For example, technologies for combustion products that are closely linked with many other technologies are given more weights than technologies for wigs that have fewer technologies linked with them. Each dot on the scatterplot represents a country among 93 countries that are analyzed, and the red line indicates the quadratic prediction of weighted number of new technologies with RTA larger than 1 at time t+5 according to weighted number of technologies with RCA larger than 1 at time t. The results show that there is a strong positive relationship between the current number of technologies with production advantages and future number of technologies with new technological advantages. The path-dependence can be consistently observed across the five time periods, and similar pattern is also shown in graphs using unweighted numbers.

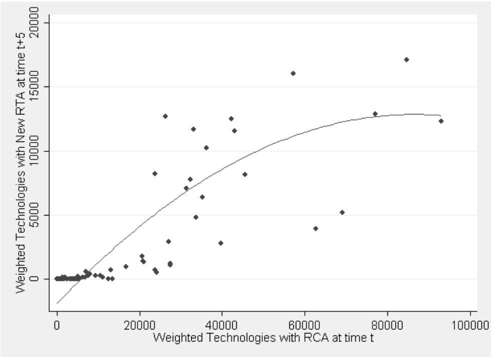
By including the proximity for the same analysis, it is also possible to test whether the production experience influences the development of technological advantage in the nearby technologies. **Figure 3-2** illustrates the relationship between average technology density at time t and number of technology with new comparative advantage at time $\mathrm{t} + 5$. The difference between **Figure 3-1** is that by including the concept of proximity and density, the analysis can trace whether producing experience in similar technologies helps a country accumulate experience and therefore develop technological capability in the future. The strong positive relationship suggests that a country is more likely to acquire new technological advantage if it has accumulated production experience in connected technologies in technology space. For example, following the result of this figure, a country with production experience in machinery will be likely to develop a new technology in electronics, which is close to the machinery in the technology space.



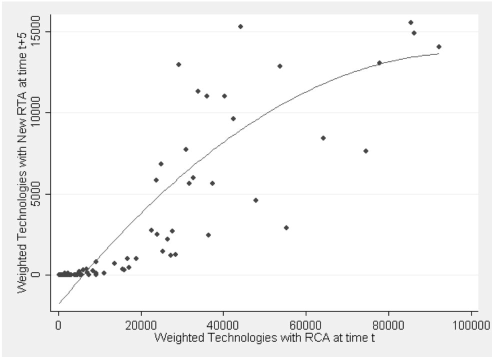
a) Year 1985



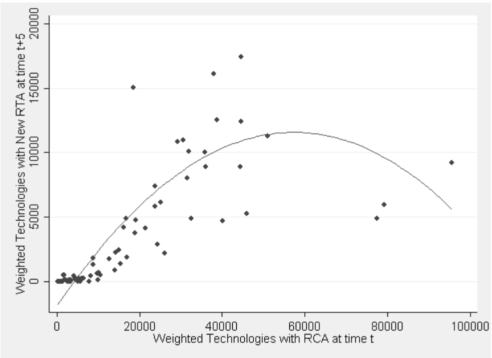
b) Year 1990



c) Year 1995



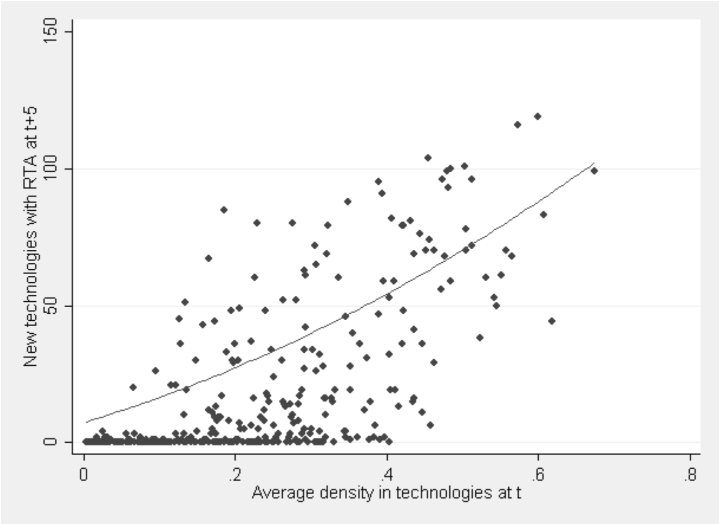
d) Year 2000



e) Year 1995

Note: Each circle in the scatterplot represents each country, and a country has comparative advantage if RCA or RTA is equal or larger than 1. The red line indicates the quadratic prediction for correlation.

Figure 3-1. Relationship between weighted number of technologies with RCA at t and weighted number of new technologies at $t+5$ in 93 countries, from 1985 to 2005.



Note: each circle in the scatterplot represents a country of a specific year, and a country has comparative advantage if RCA or RTA is equal or larger than 1.

Figure 3-2. Relationship between the average density of technologies at t and number of new technologies with RTA at t+5, from 1985 to 2005 with 5-year interval.

The statistical figures suggest that countries with more production capabilities are more likely to develop new technological capabilities, especially if the production capabilities are cumulated in nearby technologies. For additional information, the histogram of probability of having new technology after 5 years based on the current levels of production density can show the relationship between production density and emergence of technological advantage. shows the results for the overall time periods.

Figure 3-3 shows that as the production density increases, probability of acquiring new technological advantage increases. The result is in line with the hypothesis that production experience nearby a product leads to higher probability of technological capability emergence. This pattern is more evident in the case of countries with high ratio of manufacturing in exports (more than 70%), where the lowest density class shows lower probability of transition and the highest density class shows higher probability of transition to new technology.

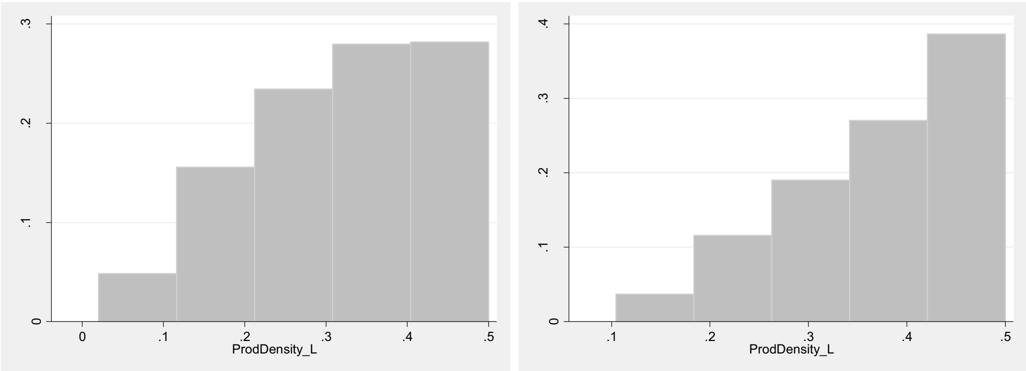


Figure 3-3. Probability of transitioning into new technologies at t+5 based on the production density at t, for all countries (left) and countries with high manufacturing ratio (right).

The statistical evidence suggests that there exists a close relationship between production experience in nearby products and emergence of technological capability. Same results in the econometric analysis would support the hypothesis that there exists a dynamic learning process from production to innovation at national level. As in the statistical analysis, the econometric analysis covers the time period divided into 5-year year intervals, and estimates the equation presented previously (Eq. (3-1)). **Table 3-1** presents the result of this analysis.

Table 3-1. Econometric results for the estimation of technological advantage to production density.

Dependent variable $RTA_{c,i,t+5}$	**Linear probability model**			**GLM**			**Probit**		
	0-30 (1)	**30-70 (2)**	**70-100 (3)**	**0-30 (4)**	**30-70 (5)**	**70-100 (6)**	**0-30 (7)**	**30-70 (8)**	**70-100 (9)**
$RTA_{c,i,t}$	0.342***	0.338***	0.38***	1.515***	1.448***	1.612***	0.826***	0.612***	0.706***
	(0.151)	(0.011)	(0.006)	(0.074)	(0.05)	(0.027)	(0.057)	(0.045)	(0.025)
$ProdDensity_{c,i,t}$	0.429***	0.193***	0.261***	2.2449***	0.916***	1.232***	1.383***	0.48*	0.844***
	(0.117)	(0.068)	(0.023)	(0.607)	(0.324)	(0.107)	(0.398)	(0.249)	(0.086)
Constant	0.371***	0.348***	0.205***	-0.594***	-0.656***	-1.301***	-0.27***	-0.168**	-0.684***
	(0.02)	(0.021)	(0.011)	(0.104)	(0.1)	(0.051)	(0.075)	(0.08)	(0.04)
R-squared	0.125	0.118	0.152						
Optimization				Maximum Likelihood	Maximum Likelihood	Maximum Likelihood			
(1/df) Pearson				1.000	1.000	1.000			
Log-likelihood							-2180.0	-4596.8	-15178.3
Observations	3,730	7,556	25,002	3,730	7,556	25,002	3,730	7,556	25,002

Note: Standard errors are shown in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Based on the hypotheses and statistical evidence, the econometric analysis tests whether lagged value of dependent variable, which is the dummy variable for RTA of a product class, and lagged value of product density around that product class have positive effect on the dependent variable. In order to test these hypotheses, the linear probability model is first implemented for each groups of countries categorized by their manufacturing ratio in exports. Columns (1) through (3) report the results for these estimations. The results support the argument that history matters in development of technological capability, such that the presence of RTA in the previous period will increase the probability of having RTA in the next period too. In addition, the results show that production experience matters in development of technological advantage. Lagged production density, measuring the production experience in nearby products in the previous period has significant and positive effect on RTA. This suggests that technological capability is likely to show some degree of persistence over time, and production capabilities in similar products will help technological capability to develop in the future. These results are consistent across country groups of manufacturing ratio, with positive and significant effects of lagged RTA and lagged production density. This implies that learning occurs from production regardless of industrial structures of countries, and incorporating production capability can suggest another way of interpreting path-dependency character of technological development.

As mentioned in the previous section, estimation of linear probability model can involve inefficiency and give biased results. Columns (4) through (6) give results from using binomial generalized linear models. Again, the lagged dependent variable and lagged production density show positive and significant influence on technological advantage for all groups of countries. Probit model is another way to deal with biases coming from having a binomial dependent variable. Columns (7) through (9) show the estimation using probit model across groups of countries. There are some differences in significance, but the results are consistent with results using other methods, with positive and significant effects of independent variables. Again, the results are consistent across country groups, suggesting that not only technological capability in the past but also production capability in nearby products help technology capability to develop or continue in the future.

For robustness check of the estimation result, the additional estimation uses production density calculated based on the proximities among products. Whereas the previous estimation translated the export data into patent classification in order to analyze the influence of production on technological emergence, this time the same hypothesis is tested with the patent data translated into export classification. Because the ALP concordance uses different probability for SITC to IPC translation from IPC to SITC translation, proximities are different among nodes of the space map of the previous estimation. Previous estimation considered each node as a technology of a technology space, and the new estimation would consider each node as a product of a product space. **Table 3-2** shows the result of the estimation. Also, for the robustness check in econometric estimation, system GMM estimation has been added in **Table 3-3**. Although the countries with low manufacturing ratio showed positive yet insignificant effect of production on technological emergence, other types of countries maintained the positive and significant effects during regression.

Table 3-2. Econometric results of estimation from proximity based on product space

Dependent variable $RTA_{c,p,t+5}$	**Linear probability model**				**GLM**			
	0-100 (1)	0-30 (2)	30-70 (3)	70-100 (4)	0-100 (5)	0-30 (6)	30-70 (7)	70-100 (8)
$RTA_{c,p,t}$	0.477***	0.401***	0.419***	0.508***	2.08***	1.724***	1.802***	2.246***
	(0.003)	(0.009)	(0.007)	(0.004)	(0.016)	(0.042)	(0.033)	(0.022)
$ProdDensity_{p,t}$	0.03**	0.099*	0.012	0.114***	0.151***	0.494*	0.061	0.619***
	(0.01)	(0.059)	(0.026)	(0.012)	(0.051)	(0.291)	(0.131)	(0.063)
Constant	0.263***	0.341***	0.328***	0.206***	-1.031***	-0.662***	-0.718***	-1.342***
	(0.003)	(0.008)	(0.007)	(0.004)	(0.016)	(0.04)	(0.33)	(0.022)
R-squared	0.228	0.163	0.176	0.262				
Optimization					Maximum Likelihood	Maximum Likelihood	Maximum Likelihood	Maximum Likelihood
(1/df) Pearson					1.000	1.000	1.000	1.000
Observations	77,131	11,058	18,693	46,112	77,131	11,058	18,693	46,112

Note: Standard errors are shown in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Table 3-3. Econometric results of estimation from proximity based on system GMM

Dependent variable $RTA_{c,p,t+5}$	**System GMM**		
	0-30 (1)	30-70 (2)	70-100 (3)
$RTA_{c,p,t}$	0.086***	0.112***	0.201***
	(0.005)	(0.004)	(0.004)
$ProdDensity_{p,t}$	1.227	0.837**	0.308***
	(0.812)	(0.351)	(0.09)
Constant	2.391***	1.788***	1.178***
	(0.131)	(0.104)	(0.417)
AR(1)	-11.99	-22.60	
(*p*-value)	(0.000)	(0.000)	
AR(2)	1.87	-0.43	
(*p*-value)	(0.061)	(0.670)	
Optimization			
Observations	3,879	7,818	25,630

Note: Standard errors are shown in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

The results are in accordance with what previous evidence showed. Column (1) and (5) shows the overall estimation of all countries using linear probability model and GLM. Results support the hypothesis that production capability of nearby products would lead to higher probability of acquiring technological capability of the product. The results hold for most groups of countries based on their manufacturing ratio, especially with countries with high- and low-ratio of manufacturing that showed strong correlation between production experience with technological emergence. Countries with moderate ratio of manufacturing in exports did not show significance in production density to technological emergence, yet still showed positive sign.

To summarize, both the statistical evidence and econometric analysis support the hypothesis that production experience in nearby products or nearby technologies helps technological capability to develop in the future. The results show that the evolution of technological structure is multilaterally path-dependent, because not only the technological capability in the past matters, but also the production capability shapes the future technological capability

3.6 Conclusion

Based on previous studies using product space or technology space arguing for path-dependent nature of technological evolution (Boschma et al., 2015; Colombelli et al., 2014), and using network methodological framework suggested by Hidalgo et al. (2007), this chapter studied the emergence of new technologies at the country level. This study focused on whether the industrial structure and production capability of countries influence the future development of technological capability of countries, especially in nearby products that they are already exporting.

The results show that production advantage in the past is positively associated with emergence of technological advantage in the future, and this positive relationship also holds after considering the proximity among technologies. Therefore, production advantage in the past in related technologies can be a source of future technological advantage. These results contribute to the understanding of path-dependence characteristic in emergence of technological advantage, and highlight on the role of production as an alternative way to promote innovation.

As described in the previous sections, production advantage in the past is found to be significant in development of new technological advantage in the future. This relationship suggests another way of interpreting technological path-dependence by incorporating the perspective of learning from production. By adding this novel empirical finding for linkage between production and innovation, the results provide implications for both innovation theories and innovation policies.

Chapter 4. Technological competence as a driver of industrial diversification

4.1 Introduction

This study aims to provide the empirical evidence on national-level technological competence as a driver of industrial diversification, and more specifically provide rationale for unrelated diversification by interpreting unrelated diversification as the result of technologically related diversification. By doing so, this chapter provides empirical evidence on diversification based on technological capabilities, and also enriches the discussion on unrelated diversification. This study analyzes the link between product diversification and technological competence at the national level, based on the path-dependent diversification across products and technologies.

Classic literatures including Lewis (1955), Kuznets (1966), and Rostow (1959) interpreted economic development of countries as changing industrial structure of production, such that the countries' resources move towards industries with higher productivity. From the seminal study by Penrose (1959), resource-based viewpoint of diversification has defined diversification as result of the spreading out of the resources to possible products and services (Chatterjee & Wernerfelt, 1991; Montgomery & Wernerfelt, 1988; Teece, 1982). These studies view resources as inputs during production process, and that these resources can be used to produce different products for different purposes in different combinations. Choices of using excess resources lead to diversification, and mix-and-match of these resources make the difference in future growths.

Evolutionary studies, on the other hand, provide capability-based theoretical background to interpret dynamic diversification patterns. These studies argue that diversification is also path-dependent process, and that the successful introduction of new products is closely related, and highly depends upon the existing knowledge stock (Nelson & Winter, 1982; Teece et al., 1994). New products are not the result of Recent studies by Hidalgo et al., (2007) and Hidalgo & Hausmann (2009) expanded this discussion and explained the diversification patterns of countries as learning process, and argued that the current industrial structures of countries determine the future state of industrial structures. These studies state that diversification paths of countries depend on what they already have been producing, and the ability to accumulate capability – both tangible and intangible inputs – to produce more sophisticated products. Nevertheless, previous studies describe the role of technology only briefly or implicitly, and consider it as one of the many capabilities and consider it as an exogenous variable in explaining the diversification patterns.

This chapter tries to fill the gap between the two theoretical breadths by focusing on the role of technological competence as a key resource during product diversification of countries, and that the country's diversification process is path-dependent to its technological structure. Technology, one of the key resources in the society, co-evolves with production (Pavitt, 1998) and positively influences productivity (Dosi et al., 2017;

Hall & Mairesse, 1995). This work brings several contributions to the current stream of diversification literature. First, it provides empirical evidence to analyze factors of national diversification, whereas previous studies on mostly focused on factors of firm-level diversification. Second, by bringing technology as the key factor in diversification, this study adds technological perspective to the diversification literature and re-emphasizes the close linkage between technology and production. Third, this study separates related and unrelated diversification to show specific effect of technological competence in each.

Based on the international export and patent data from 82 countries from 1980 to 2010, this study investigates whether countries with competence in core technologies are likely to diversify in products. In addition, the degree of diversification is decomposed into related and unrelated diversification to elucidate whether diversification from technological competence is related or unrelated. The statistical and econometric results support that countries with technological competence in core technologies experience increase in diversification. Also, whereas technological competence had less significant influence on related diversification, it had significant relationship with unrelated diversification.

The rest of this chapter is aligned as follows. Section 2 reviews the literatures on the factors of diversification, along with the different rationales behind related and unrelated diversification. Section 3 describes the data, and Section 4 explains the methodology. Section 5 presents the empirical results including descriptive statistics and econometric estimation. Finally, Section 6 ends the chapter with the conclusion with policy implications.

4.2 Previous Studies

4.2.1 Technology as a factor of diversification

The question of what a country produces has been the key question among economists, especially since there is a strong relationship between the industrial structure of a country and its economic growth (North, 1955). Starting with David Ricardo's *Principle of Political Economy and Taxation*, the conventional perspective on the diversification, specialization, and following changes in industrial structures of countries has focused on given resources, such as but not limited to physical and human capital, and natural endowments. In the classical Ricardian trade theory, countries decide what to produce and specialize on it by following their comparative advantage. From the resource-based view, diversification is the result of using idle resource to a number of different activities (Penrose, 1959; Teece, 1982). Whereas Ricardo explained the differences among countries' comparative advantages by differences in labor productivity, more studies added that international patterns of diversification depend on the different endowments of countries. The primary example is the Heckscher-Ohlin-Samuelson (HOS) model, which explains that the different export patterns stem from the comparative advantage from different endowments and different factors of production. The HOS model assumes a setting with two goods, two countries, and two resources of labor and capital. Here, the countries decide what to export based on their relative endowments of resources, and more intensively exploit the resource they are relatively abundant with. This factor-endowment theory has its advantage in describing a simple trade model based on comparative advantages, and triggered a number of subsequent studies that supplemented the argument both empirically and theoretically (Leontief, 1953; Leamer, 1980; Krugman, 1985). Yet, the model involves too many assumptions such as free trade, perfect competition and mobility of factors across countries, identical demand, and lastly, identical technology.

Studies on international trade have continuously kept their interest on the technological change, in contrast with most of the other economic fields that consider the technology variable as a ubiquitous "black box" (Rosenberg, 1982) in the production function and de-emphasize the differentiated and cumulative nature of technology. There have been a number of studies that tried to supplement the existing models by incorporating technology as another factor of diversification. (G. M. Grossman & Helpman, 1991) also presents an advanced model of Ricardian growth model incorporating the technological viewpoint, and suggests that a country specializing in high-technology sector enjoys a faster growth rate. Davis (1995) suggests the technological differences across countries induce specialization and trade by introducing Ricardian trade theory to the HOS framework. From neoclassical perspective, as in the Ricardian model where countries specialize on goods they have advantage in, Krugman (1982) studies the trade patterns stemming from technology gaps and different technological intensities of goods. In his following study, Krugman (1985) sets up a model where the technological level of two countries differ, and at the same time the goods have different technology intensity. The results from this study argue that technological progress in a technologically advanced country widens the technological gap, and creates greater chances for further trade, therefore benefitting both types of technologically more advanced and less advanced countries. On the other hand, if the technological gap gets smaller, benefit from trading will be eliminated. Unlike a number of neoclassical studies, this study does not consider technological capability as an endowment, but a factor resulting from human action.

From the Schumpeterian idea of technological advantage leads to prospects of monopoly rents, the concept of 'technology gap' arose. Posner (1961) and Hufbauer (1970) point out that in dynamic economies, technological changes do not occur at once equally to all countries. Rather, a particular technological change in a country leads to difference in comparative costs. As a result, the country with technological change and following advantage in comparative costs will have first-mover advantage during the time taken for other countries to imitate that technological innovation. However, as mentioned by the author too, the model does not take account into the specialization after the latecomer countries caught up with technology gap. Mere static economies do not follow even after the other countries imitated the technological change, since the importance of technology in determining trade flows is not impermanent since countries leading technological innovation act to prolong the lead from the innovation (Dosi & Soete, 1988). The technological advantage does not last long, and therefore the developed regions must keep running to stay in the same place (Krugman, 1979). There is also a line of product cycle theories which depict the trade patterns similarly, by looking at technology as a part of a market structure factors, such as product differentiation and market entry (Vernon, 1966). Developing from this perspective, theories of technological innovation put dynamic emphasis on international competition, and link post-Schumpeterian evolutionary models with economic growth (Aghion & Howitt, 1992) and international trade patterns (Saviotti & Frenken, 2008).

In evolutionary economics, the studies consider topic of specialization and diversification as the result of innovative activities across industries (Nelson & Winter, 1982), and explain the path-dependent nature, or lock-in (Arthur, 1989) of these innovation. In other words, new activities or emergence of new industries highly depend on what the countries have done in the past, and therefore new industries are likely to emerge and be successful if they are closely related to the current industrial structure (Frenken & Boschma, 2007). Many studies emphasize the importance of path-dependence in industrial diversification at regional level (Boschma et al., 2013; Martin & Sunley, 2006; Neffke et al., 2011) and at national level(Bahar et al., 2014; Felipe et al., 2012; Hidalgo et al., 2007; Minondo, 2011; Pinheiro et al., 2018). The same path-dependence can be applied to the pattern of knowledge diversification (Boschma et al., 2015; Colombelli et al., 2014; Kogler et al., 2017).

However, there are two key limitations on the previous studies on path-dependent nature of industrial diversification. First, they do not distinguish the technological capability and production capability, but considers emergence of new industry as innovation, and comparative advantage in export as capability (Eum & Lee, 2019). Here, technological competence or accumulated knowledge is just a one of the implicit factors that may affect the comparative advantage in exports, and therefore the linkage between current technological capability and future industrial diversification is unclear. Yet there should be a clear distinction between production with technology and production without technological capability (Neffke et al., 2011), considering the clear difference between know-how and know-why (Lall, 2000b). Therefore, distinguishing two different types of capabilities each representing production and technological capability can help clarifying the role of technology during diversification. If firms and countries are more likely to add on to what they already have been doing (Dosi et al., 1990; Nelson & Winter, 1982), it is also plausible that firms and countries add on to what they already know. Second, despite a wide theoretical discussion on the industrial emergence from evolutionary point of view since Nelson & Winter (1982), the discussion lacks empirical evidence especially in clear relationship between the technological capability and industry emergence or diversification at national level. Many studies involve case studies and qualitative reasoning, yet do not cover a wide range of time period or diverse countries. There is a need to interpret how economic paths emerge and develop from a path dependence and co-evolutionary perspective (Martin & Sunley, 2006).

Therefore, it is possible to enrich the current discussion on industrial diversification from evolutionary point of view by including the effect of knowledge competence of countries on industrial diversification, with multilateral viewpoint taking both industrial and knowledge levels into account. Previous studies acknowledge the importance of technology as a key factor in industrial diversification, but the path-dependent characteristic from technological capability to industry diversification needs further explanation. Hence, identifying and testing the relationship between the two through a cross-country analysis will provide a reliable evidence to previous diversification studies.

Hypothesis 1: Technological capability is a key factor of industrial diversification

4.2.2 Different factors and patterns of related and unrelated diversification

A large number of firm-level strategic management and industrial organization studies tried to explain how and why diversification takes place to related and unrelated fields (Rumelt, 1982; Teece, 1982). In the seminal work of Penrose (1959) on the topic of firm growth, the author interprets the final products as representative of using its internal resources in various ways, and following studies built on her idea. Firm-level studies diversification also can be approached from the neoclassical cost function, in which a firm assumes profit-maximizing entities under competitive product and capital markets, facing no transaction costs. However, these assumptions cannot lead to a theory of the multiproduct firm (Teece, 1982). On the other hand, from resource-based approach, a firm's products and services stem from a common pool of resources (Chatterjee & Wernerfelt, 1991; Montgomery & Wernerfelt, 1988; Penrose, 1959), and the firm tries to exploit the production opportunities by the combination of its used and unused resources. The resources can be applied to different ways to result in different products and services (Ng, 2007) and knowledge assets of firms can play an important role during diversification

(Miller, 2004) and building competence (Kang et al., 2019).

The resource-based perspective on diversification regards related diversification as a favorable choice in organizational expansion to unrelated diversification (Montgomery & Wernerfelt, 1988; Rumelt, 1982; Teece et al., 1997). From this perspective, diversification building upon existing capabilities is more likely to be meritorious (Teece et al., 1997) and unrelated diversification is more likely to be risky (Montgomery & Singh, 1984), because “the general direction of innovation in the firm is not haphazard but is closely related to the nature of existing resources” (Penrose, 1959). Here, Penrose (1959) mentions that the resource is not limited to physical capital but includes technological capability, and argues that diversification and expansion depend primarily on a high degree of technical competence in specialized areas of manufacture. Competence is built on the capabilities and resources that a firm accumulates over time, and the connection between the current competence and productive opportunities leads to diversification (Kor & Mahoney, 2000). However, more empirical studies found evidence that firms diversify more broadly than what the resource-based studies expected (Chatterjee & Wernerfelt, 1991; Ng, 2007). Specifically, in technology-intensive sectors such as pharmaceuticals showed significant diversification (Argyres, 1996; McGrath & Nerkar, 2004) and patterns of leveraging resources to advance into newer sectors (Eisenhardt & Martin, 2000). Despite the usefulness of resource-based view in setting a framework for comparative advantage within firms, it has limitations in explaining the unexpected path-breaking strategies since it not only underestimates change in dynamic markets but also is less useful in predicting the sources of future advantage (Eisenhardt & Martin, 2000).

Recently, more regional and national-level studies approached the question of factors and patterns of related and unrelated diversification. Most studies reach the same conclusion with the firm-level resource-based studies, and argue that countries and regions are more likely to advance to the industries that are related to what they already are capable of (Boschma et al., 2015; Hidalgo et al., 2007; Neffke et al., 2011; Zhu et al., 2017). These study start from the assumption that advancing to the related industries require similar institutions, human resources, technology, and other inputs. However, more recent studies point out that regions and countries also show deviating patterns and potential benefits of unrelated diversification (Boschma, 2017; Pinheiro et al., 2018). Whereas there are studies on the aftermath of national-level unrelated diversification, there still is a room to discuss on the factor of unrelated diversification.

Therefore, it is important to provide additional discussion on the topic of factors of diversification by dividing the types of diversification into related and unrelated diversification (Palepu, 1985). Yet, there are not enough empirical studies that considers technological capability as a key factor of diversification, or more specifically, unrelated diversification. Testing the effect of technological capability on future related and unrelated diversification will support the past resource-based discussions of the importance of technological competence, and also provide an alternative viewpoint in interpreting unrelated diversification as a non-anomaly.

Hypothesis 2: Technological capability has different effects on related and unrelated diversification

4.3 Data

This study uses three types of datasets covering from 1980 to 2010 to investigate the linkage between technological competence and product diversification: export dataset to measure the degree of diversification, patent dataset to proxy the technological competence, and concordance matrix that links the export and patent datasets. The combined dataset with export and patent data includes 82 countries with both patent and export data available.

First, the export dataset uses the World Trade Flows data (Feenstra et al., 2005), which is based on the UN Comtrade statistics with additions and corrections. This data is organized by the Standard International Trade Classification (SITC) 4-digit, revision 2, and covers data until year 2000. Since this data does not include export data from 2000, this study constructed a new dataset by adding export data from 2001 through 2011 from UN Comtrade. The additional data is also based on SITC 4-digit, revision 2, following the World Trade Flows data. The analysis acknowledges that trade items change over time, and more recent revisions such as revision 3 updated in 1986 and 4 updated in 2006 can represent more exact product diversification. However, considering that newer revisions also have limitations in representing trades occurred in earlier years, this study uses revision 2 in order to keep the consistency of analysis over three decades.

Second, the patent dataset uses the patent statistics by Organization for Economic Co-operation and Development (OECD) Directorate for Science, Technology and Industry, from OECD statistics (OECD,Stat). OECD patent statistics collects United States Patent and Trademark Office (USPTO) and European Patent Office (EPO) patents, and sort the number of applied and granted patent data by technology by country. This study uses the number of USPTO patent grants from 1980 to 2010. The data is classified by International Patent Classification (IPC) 4-digit, sorted by inventor's country of residence. In case of multiple inventors or multiple subclasses of IPC, a single patent may be divided into multiple countries or IPC classes, so a country often may have number of patents not in integers.

Lastly, Algorithmic Link with Probabilities (ALP) (Lybbert & Zolas, 2014) methodology's concordance matrix links the export dataset and patent dataset. ALP use keyword extraction from industry descriptions, and match the results with patent data through a probabilistic framework. Since the two datasets have different classes of SITC and IPC, they should be translated from one to another in order to analyze the relationship between the technological competence and product diversification on the same ground. Among a number of correspondence matrix options such as the Yale Technology Concordance (YTC) (Kortum & Putnam, 1997), ALP provides a more effective meso-level and macro-level mapping to industries. This study links 629 4-digit IPC codes (Ver. 8) to 785 4-digit SITC codes (Rev. 2). Linking the two classes leads to a matching between technology and product at a sufficiently disaggregated level to keep track of diversification process (Dosi et al., 2017).

Considering that the analysis estimates the relationship from technology to production, it is necessary to group the countries by their manufacturing ratio to merchandise exports. Manufacturing ratio is often considered as an important factor in structural diversification (Johnson & Noguera, 2017; Weiss, 2015), and would better represent each country groups than income levels. In some estimations, it is necessary to group countries based on their manufacturing ratio to merchandise exports. This study uses the manufacturing ratio data from World Development Indicators by the World Bank, and divides the countries into three groups to high, middle, and low. Countries with high manufacturing ratio have the ratio of higher than 70 percent, countries with middle manufacturing ratio have the ratio between 30 to 70 percent, and countries with low manufacturing ratio have the ratio lower than 30 percent. As a result, high ratio group has 27 countries, middle ratio group has 31 countries, and low ratio group has 24 countries.

4.4 Model

The dependent variable in this study is the change in degree of product diversification using an entropy index. A number of previous studies used the entropy index as a measure of diversification in both product (Jacquemin & Berry, 1979; Varadarajan, 1986) and technology (Miller et al., 2007). Here, this study constructs three types of diversification – total, related, and unrelated – based on SITC classes (Palepu, 1985). The total diversification TD_{ct} is defined as follows:

$$TD_{ct} = \sum_{i=1}^{785} XS_{cit}\, ln(\frac{1}{XS_{cit}}) \quad \cdots\cdots \quad (4\text{-}1)$$

where $\boldsymbol{XS_{cit}}$ is the export share of SITC 4-digit product class *i* in country *c* at time *t* ($XS_{cit} = X_{cit}/X_{ct}$), and $\boldsymbol{X_{cit}}$ is the export volume of SITC 4-digit product class *i* in country *c* at time *t*, and $\boldsymbol{X_{ct}}$ is the total export volume of country *c* at time *t* ($X_{ct} = \sum_{i=1}^{785} X_{cit}$). In other words, the calculation above is the weighted average of the export shares of industry classes, and the weight for each class is the logarithm of the inverse of the share. Therefore, this measurement has its advantage in including both aspects of diversification: the absolute number of product classes that the country is exporting and relative importance of each class (Palepu, 1985).

By decomposing this total diversification measure (Jacquemin & Berry, 1979; Kim et al., 2016; Palepu, 1985), it is also possible to obtain measures of related diversification $\boldsymbol{RD_{ct}}$ and unrelated diversification $\boldsymbol{UD_{ct}}$ as follows:

$$TD_{ct} = \sum_{j=1}^{69} XS_{cjt}\, ln\left(\frac{1}{XS_{cjt}}\right) + \sum_{j=1}^{69} XS_{cit}(\sum_{i \in j} XS_{cit}\, ln(\frac{1}{XS_{cit}}))$$

$$TD_{ct} = UD_{ct} + RD_{ct} \quad \cdots\cdots \quad (4\text{-}2)$$

where $\boldsymbol{XS_{cjt}}$ is the is the export share of SITC 2-digit product class *j* in country *c* at time *t* ($XS_{cjt} = X_{cjt}/X_{ct}$). In other words, the first part of the decomposed calculation of total diversification above is the unrelated product diversification across 69 SITC 2-digit product classes, and the second part is the related product diversification across 785 SITC 4-digit product classes within the 69 SITC 2-digit product classes.

The change in degree of product diversification uses 5-year time gap between the periods, and calculates how each measures of diversification changed over the time periods. The difference in degree of total, related, and unrelated diversification between time t and $t-5$ can be expressed as follows:

$$TDDiff_{c,t} = TD_{c,t} - TD_{c,t-5}$$
$$RDDiff_{c,t} = RD_{c,t} - RD_{c,t-5}$$
$$UDDiff_{c,t} = UD_{c,t} - UD_{c,t-5} \quad \text{(4-3)}$$

where $\boldsymbol{TDDiff_{c,t}}$ is the change in degree of total diversification between time t and $t-5$, $\boldsymbol{RDDiff_{c,t}}$ is the change in degree of related diversification between time t and $t-5$, and $\boldsymbol{UDDiff_{c,t}}$ is the change in degree of unrelated diversification between time t and $t-5$, respectively.

The key independent variable is the core-technology competence (J. Kim et al., 2016) of countries. Considering the different technological backgrounds of countries, a unit-free measurement of technological competence is more useful than the mere counts of patent grants. Revealed technology advantage (RTA) (Patel & Pavitt, 1997), a measurement that uses patent data instead of export data as in revealed comparative advantage (RCA) (Balassa, 1965), can identify the comparative advantage of countries in technological fields.

RCA and RTA are defined as follows:

$$RCA_{cit} = \frac{x_{cit}}{\sum_i x_{cit}} \Bigg/ \frac{\sum_c x_{cit}}{\sum_{c,i} x_{cit}}$$

$$RTA_{ckt} = \frac{x_{ckt}}{\sum_k x_{ckt}} \Bigg/ \frac{\sum_c x_{ckt}}{\sum_{c,k} x_{ckt}} \quad \cdots\cdots (4\text{-}4)$$

where *c* stands for country, *i* stands for product class (SITC), *k* stands for technology class (IPC), *x* for number of patent granted at time *t*.

RTA considers that a country has a comparative advantage in a specific technology class if the patent share of a country of a technology class is equal to or greater than that of the world. If the RTA value is equal or greater than 1, the country has a comparative advantage in that technology. If the RTA value is less than 1, the country does not have a comparative advantage in that technology (Soete, 1987). Following previous studies on measuring technological competence (J. Kim et al., 2016; Patel & Pavitt, 1997), this study calculates the maximum value of RTA multiplied by number of patent grants of the corresponding technology class, in order to measure the country-specific core-technology competence ***CORETEC*** using the technology class-specific RTA as follows:

$$CORETEC_{ct} = ln[max\{RTA_{ckt}x_{ck}\}] \quad \cdots\cdots (4\text{-}5)$$

In addition, this study includes some control variables to represent country-specific characteristics that may affect the change in degree of diversification over time. Given that the economic size and growth influence the diversification patterns (Aw & Batra, 1998; Christensen & Montgomery, 1981; Siegel et al., 1995) the export volume (ExpVol) and export growth rate (ExpGrowth) are included in order to control the effect of trade characteristic of a country on diversification.

This study uses 5-year time lag to measure the impact of technological competence on future product diversification, following previous literatures that analyzed the diversification patterns of countries and regions based on the current capability (Boschma et al., 2013; Colombelli et al., 2014; Hidalgo et al., 2007). Covering 1980 through 2010, this study includes seven time periods with 5-year time gap between the time periods. Also, the analysis uses 3-year average instead of a single year. For example, the average data of 1979, 1980, and 1981 is used instead of 1980 only. This way, the analysis can cover more years of data, avoid the data fluctuations from year-specific characteristics, and also avoid disturbance coming from 18-month time gap between the application and publication of a patent. Therefore, to be precise, both export and patent datasets covers years from 1979 to 2011.

This chapter aims to estimate how the current core-technology competence influences future product diversification. For empirical analysis, this chapter adopts a fixed-effect estimator for the panel regression in order to control the omitted variables that may affect the dependent variable. The econometric estimation can be written as follows:

$$\boldsymbol{TDDiff_{c,t} = \beta_0 + \beta_1 CORETEC_{c,t-5} + \beta_2 X_{c,t-5} + \beta_3 Z_{i,t-5} + \beta_4 Y_{c,t-5} + u_c + \varepsilon_{c,t}} \cdots \text{(4-6)}$$

where the dependent variable $TDDiff_{c,t}$ is the change in degree of total diversification of country c at time t ($TDDiff_{c,t} = TD_{c,t} - TD_{c,t-5}$). Independent variable $CORETEC_{c,t-5}$ is the core-technology competence of country c at time $t-5$. Country-specific control variables $X_{c,t-5}$ include the control variables including export volume, export growth rate, and GDP per capita, and $Z_{i,t-5}$ indicates the industry control variable, the industry growth rate. $Y_{c,t}$ indicates the year dummy variables, and the estimation also includes u_i as the unobserved country-specific characteristics that may have correlation with the independent variables during the fixed-effect estimation, and the error term $\varepsilon_{c,t}$.

As explained earlier, the dependent variable $TD_{c,t}$ can be decomposed into two parts of related diversification and unrelated diversification. For the second hypothesis, this study tests whether the core-technology competence influences future related diversification and unrelated diversification. The econometric estimation can be written as follows:

$$\boldsymbol{RDDiff_{c,t}} = \beta_0 + \beta_1 \boldsymbol{CORETEC}_{c,t-5} + \beta_2 \boldsymbol{X_{c,t-5}} + \beta_3 \boldsymbol{Z_{i,t-5}} + \beta_4 \boldsymbol{Y_{c,t-5}} + u_c + \varepsilon_{c,t} \cdots\cdots \text{(4-7)}$$
$$\boldsymbol{UDDiff_{c,t}} = \beta_0 + \beta_1 \boldsymbol{CORETEC}_{c,t-5} + \beta_2 \boldsymbol{X_{c,t-5}} + \beta_3 \boldsymbol{Z_{i,t-5}} + \beta_4 \boldsymbol{Y_{c,t-5}} + u_c + \varepsilon_{c,t} \cdots\cdots \text{(4-8)}$$

where the dependent variable $RDDiff_{c,t}$ is the change in degree of related diversification of country c at time t ($RDDiff_{c,t} = RD_{c,t} - RD_{c,t-5}$), and $UD_{c,t}$ is the degree of unrelated diversification of country c at time t. The independent variables and control variables are kept the same as (6).

These estimations put focus on the explanatory power of the key independent variable $CORETEC_{c,t-5}$. They test the hypothesis of technological competence's effect on product diversification, and expects the result as $\beta_1 \neq 0$. If the accumulated core-technology competence has positive effect on product diversification in the future, the test will have $\beta_1 > 0$ as a result.

Table 4-1. Descriptive statistics and correlations

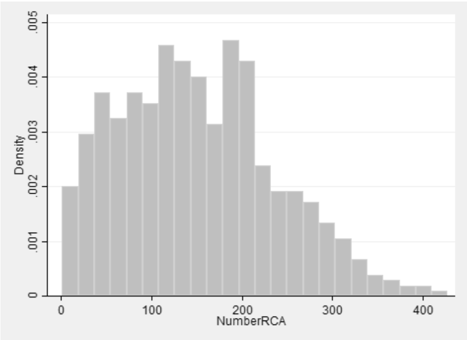
Variable	Obs.	Mean	S.D.	1	2	3	4	5	6	7
1. ΔDiversification	323,252	8.804	84.584	1.000						
2. Core-technology competence	323,252	-4.528	2.048	-0.098	1.000					
3. Export volume	323,252	19.475	3.789	-0.231	0.291	1.000				
4. Export volume^2	323,252	393.631	153.703	-0.211	0.284	0.996	1.000			
5. Export growth	323,252	136.601	425.026	0.347	-0.072	-0.333	-0.296	1.000		
6. GDPPC	323,252	9.119	1.330	-0.115	0.524	0.309	0.303	**-0.042**	1.000	
7. Industry growth	323,252	1.436	2.437	-0.129	-0.065	-0.301	-0.312	0.498	**-0.037**	1.000

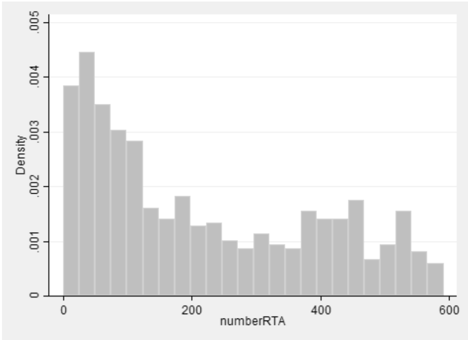
Note: The correlations in bold denote statistical significance at the 5% level

4.5 Empirical Results

The statistical and econometrical analyses aim to provide evidence for the relationship between industrial diversification and technological competence of countries. During the analyses, acquiring comparative advantage in a product is analogous to the industrial diversification. If a country has $\text{RCA} < 1$ in a specific product in a period, yet shows $\text{RCA} \geq 1$ in the next period, the country has a comparative advantage in that product class. As mentioned previously, the years are divided into five-year periods under assumption that five years are long enough to keep track of technological capability development and industry emergence. Therefore, the analyses compare emergence of RCA in years 1985, 1990, 1995, 2000, 2005, and 2010 with core-technology competence in base years 1980, 1985, 1990, 1995, 2000, 2005, respectively.

Figure 4-1 presents the distribution of countries by the number of SITC4 product classes and with two types of comparative advantage RCA and RTA in the period 1980-2010. The distribution appears skewed both in **Figure 4-1a** with number of comparative advantage in product and **Figure 4-1b** with number of comparative advantage in technology. These figures are in line with previous studies on firm-level diversification that found fewer firms are diversified in multiple technological fields (Breschi et al., 2003; Dosi et al., 2017) or product fields (Hanson, 1995; Lecocq & Demil, 2006). The same patterns emerge in country-level dataset, with a number of countries continuously showing comparative advantage in most product and technology classes across time periods (e.g. Italy, Germany, United Kingdom, United States) whereas many other countries do not.





a) Comparative Advantage in Product

b) Comparative Advantage in Technology

Figure 4-1. Distribution of countries by a) the number of SITC4 product classes with production comparative advantage RCA larger than or equal to 1, and b) the number of SITC4 product classes with technological comparative advantage RTA larger than or equal to 1.

Next, **Figure 4-2** reports the relationship between number of products with comparative advantage RCA at time t with number of products with comparative advantage RTA at time $t-5$. The results reveal that the two variables show a positive relationship, implying that technological capability in more diverse products in the past influences the production in diverse industry in the future. The statistical figures over the time periods also suggest that the positive relationship continues in all periods. The results support the previous studies that countries with technological advantage in more industries are likely to possess more diversified industries in the future. **Figure 4-3** shows the relationship between the average density of technologies at t and number of new technologies with RTA at t+5. Here, the density measure is defined as the average proximity, where proximity is the conditional probability of producing two products p_1 and p_2 with comparative advantage in both products ($\varphi_{p_1,p_2} = \min\{\mathrm{P}(\mathrm{RCA}x_{p_1} \geq 1 \middle| \mathrm{RCA}x_{p_2} \geq 1), \mathrm{P}(\mathrm{RCA}x_{p_2} \geq 1 \middle| \mathrm{RCA}x_{p_1} \geq 1)\}$). In other words, density measure is calculated by the sum of proximities between a particular product and products with RCA, divided by the sum of all proximities with other products of that product ($\omega_{p_2} = \sum_{p_1} x_{p_1} \phi_{p_1,p_2} / \sum_{p_1} \phi_{p_1,p_2}$).

The statistical evidence suggests that there exists a close relationship between current technological capability and emergence of new industries. Next, the econometric analysis tests the hypothesis that knowledge or technology acts as a key factor to product diversification. As in the statistical analysis, the econometric analysis also divides the time periods into 5-year periods, covering 1980 through 2010. The regression estimates the

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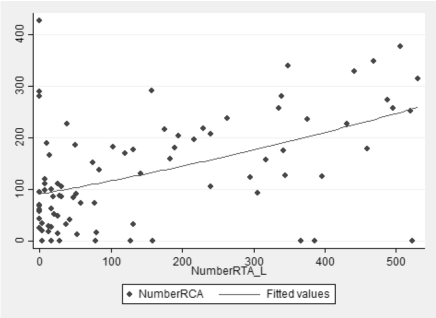
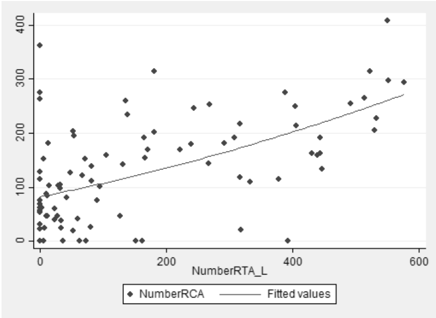
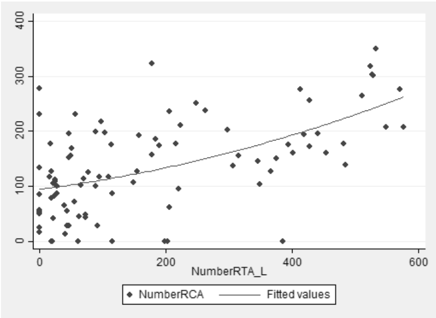
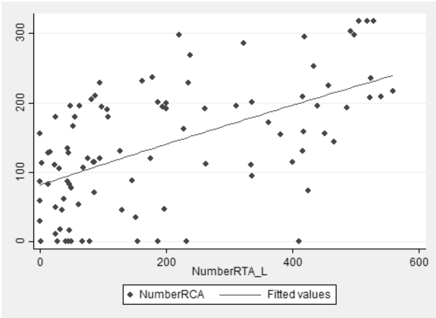


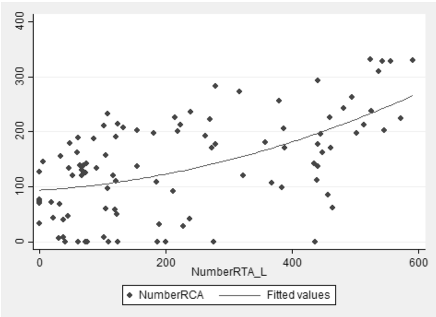


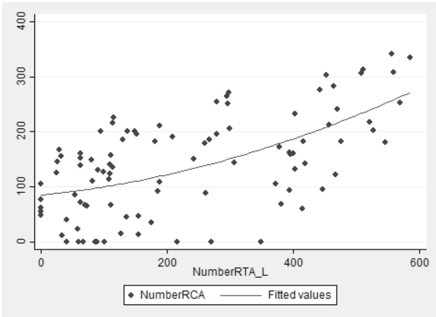
a) Year 1985 b) Year 1990





c) Year 1995 d) Year 2000

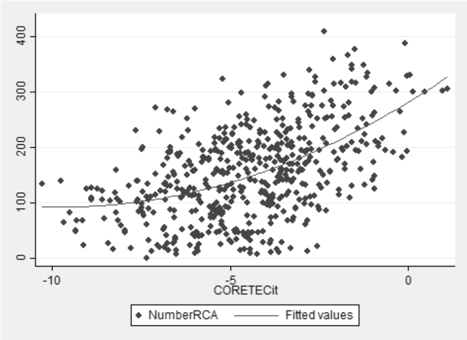


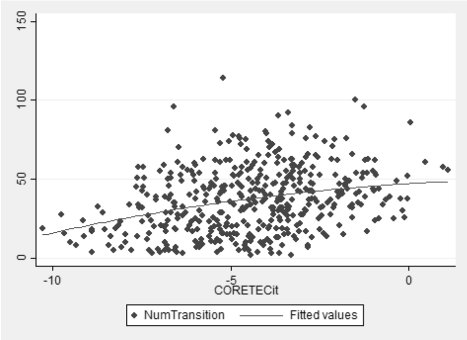


e) Year 2005 f) Year 2010

Note: each circle in the scatterplot represents a country of that year, and a country has comparative advantage if RCA or RTA is equal or larger than 1. The red line indicates the quadratic prediction for correlation.

Figure 4-2. Relationship between the number of products with production comparative advantage RCA at t and number of products with technological comparative advantage RTA at t-5, from 1985 to 2010 with 5-year interval.





a) Number of products with RCA

b) Number of Transition Products

Note: each circle in the scatterplot represents a country of a specific year, and a country has comparative advantage if RCA or RTA is equal or larger than 1.

Figure 4-3. Relationship between the average density of technologies at t and number of new technologies with RTA at t+5, from 1985 to 2005 with 5-year interval.

Based on the hypotheses and results from the statistical analysis, this econometric analysis tests whether lagged value of core-technology competence of a country, and lagged value of country-specific variables representing export volume and growth rate of export volume have significant effect on the dependent variable. The estimation uses the fixed effect model for the panel dataset, after checking its advantage over the random effect model through Hausman Test. **Table 4-1** shows the regression result of the relationship between core-technology competence and degree of total diversification of the countries. In order to test the relationship, this study used fixed-effect analysis across all countries (Columns (1) and (2)). In addition, same analysis was applied to two subsamples of countries – high core-tech competence if the level of the country's core-technology competence is above median (Columns (3) and (4)), and low core-tech competence if below median (Columns (5) and (6)).

Table 4-2. Econometric results for the estimation of change in degree of total diversification to core-technology competence

Dependent variable	All countries		Low core-tech competence		High core-tech competence	
$TDDiff_{c,t}$	**Model (1)**	**Model (2)**	**Model (3)**	**Model (4)**	**Model (5)**	**Model (6)**
$CORETEC_{c,t-5}$	0.180***	0.155**	2.697***	3.311***	0.375***	0.486***
	(0.066)	(0.066)	(0.124)	(0.127)	(0.075)	(0.076)
$ExpVol_{c,t-5}$	17.82***	20.75***	32.84***	71.54***	-4.691***	-11.46***
	(0.652)	(0.870)	(1.128)	(1.361)	(0.379)	(0.413)
${ExpVol_{c,t-5}}^2$		-0.077***		-0.934***		0.176***
		(0.011)		(0.020)		(0.008)
$ExpGrowth_{c,t}$	0.100***	0.101***	0.183***	0.187***	0.054***	0.050***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.001)	(0.001)
$GDPPC_{c,t-5}$	-14.78***	-14.54***	-15.89***	-31.35***	17.74***	16.71***
	(0.744)	(0.752)	(1.497)	(1.236)	(0.605)	(0.612)
$IndGrowth_{c,t}$	-0.007	-0.006	-0.028	-0.022	-0.023	-0.024
	(0.076)	(0.076)	(0.153)	(0.150)	(0.066)	(0.066)
Constant	-147.01***	-176.66***	-347.74***	-593.70***	-64.25***	10.56**
	(9.350)	(12.20)	(16.42)	(16.81)	(3.695)	(4.415)
R-squared (within)	0.370	0.370	0.199	0.228	0.637	0.638
Corr (u_i,)	-0.533	-0.528	-0.717	-0.771	-0.319	-0.300
Observations	323,252	323,252	147.933	147.933	175,319	175,319

Note: Standard errors are shown in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

First, across all columns, the results support that technological capability matters in industrial diversification, and stronger competence in core-technology of countries positively influences the emergence of new industries. The effects of core-technology competence are consistent across models and subsamples, with both positive and significant. The results imply that technologically competent countries are more likely to get diversified in the future. Second, among the control variables, effect of export volume is positive and significant, and that of GDP per capita is negative and significant. However, different effects appear between the two subsamples. The effect of export volume is positive and that of GDP per capita is negative in the countries with lower core-technology competence, and vice versa in the countries with higher core-technology competence. This difference is in line with the theory of stages of diversification among countries (Imbs & Wacziarg, 2003), and suggests that the technological gap between countries, or technological stages of countries can explain why countries face different factors of diversification. Export growth rate showed positive and significant effect on diversification, and industrial growth rate did not show significance in relationship.

Table 4-3. Econometric results for the estimation of change in degree of related diversification to core-technology competence

Dependent variable	**All countries**		**Low core-tech competence**		**High core-tech competence**	
$\mathrm{RDDiff}_{c,t}$	**Model (1)**	**Model (2)**	**Model (3)**	**Model (4)**	**Model (5)**	**Model (6)**
$\mathrm{CORETEC}_{c,t-5}$	-0.001	0.002	0.069***	0.093***	-0.036***	-0.032**
	(0.009)	(0.009)	(0.016)	(0.016)	(0.013)	(0.013)
$\mathrm{ExpVol}_{c,t-5}$	0.258***	0.371***	0.241***	1.737***	-0.108	-0.347***
	(0.054)	(0.068)	(0.093)	(0.138)	(0.089)	(0.100)
$\mathrm{ExpVol}_{c,t-5}{}^{2}$		-0.003***		-0.036***		0.006***
		(0.001)		(0.002)		(0.002)
$\mathrm{ExpGrowth}_{c,t}$	0.002***	0.002***	0.005***	0.005***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\mathrm{GDPPC}_{c,t-5}$	-0.562***	-0.552***	-0.157	-0.754***	0.250	0.213
	(0.089)	(0.090)	(0.150)	(0.149)	(0.140)	(0.141)
$\mathrm{IndGrowth}_{c,t}$	0.308***	-0.308***	0.248***	0.248***	0.369***	0.369***
	(0.019)	(0.019)	(0.029)	(0.029)	(0.028)	(0.028)
Constant	0.909	-0.243	-1.639	-11.14***	-0.435	2.208*
	(0.758)	(0.915)	(1.331)	(1.537)	(1.093)	(1.189)
R-squared (within)	0.030	0.030	0.021	0.023	0.044	0.044
Corr($\mathrm{u_i}$)	-0.112	-0.108	-0.024	-0.140	-0.020	-0.014
Observations	323,252	323,252	147.933	147.933	175,319	175,319

Note: Standard errors are shown in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

The dependent variable for degree of diversification can be divided into degree of related and unrelated diversification, and further analyses show how technological capability influences each type of diversification specifically. **Table 4-2** shows the regression result of the relationship between core-technology competence and degree of related diversification. Here, the effects of core-technology competence on the related diversification is insignificant across all countries, and other control variables showed same sign and significance as in the previous regression on the relationship between core-technology competence and degree of total diversification (Columns (1) and (2)). Yet, the mixed results between two subsamples are notable. In countries with low core-technology competence, core-technology competence had positive and significant effect on related diversification (Columns (3) and (4)), but negative and significant effect on related diversification in countries with high core-technology competence (Columns (5) and (6)). Overall, the influence of core-technology competence is insignificant when the sample covers all countries, and inconsistent across the subsamples.

Table 4-4. Econometric results for the estimation of change in degree of unrelated diversification to core-technology competence

Dependent variable $\text{UDDiff}_{c,t}$	**All countries**		**Low core-tech competence**		**High core-tech competence**	
	Model (1)	**Model (2)**	**Model (3)**	**Model (4)**	**Model (5)**	**Model (6)**
$\text{CORETEC}_{c,t-5}$	0.181***	0.157**	2.628***	3.219***	0.410***	0.518***
	(0.065)	(0.065)	(0.122)	(0.125)	(0.075)	(0.075)
$\text{ExpVol}_{c,t-5}$	17.57***	20.37***	32.59***	69.80***	-4.583***	-11.12***
	(0.638)	(0.851)	(1.104)	(1.334)	(0.379)	(0.415)
${\text{ExpVol}_{c,t-5}}^2$		-0.074***		-0.898***		0.170***
		(0.010)		(0.019)		(0.008)
$\text{ExpGrowth}_{c,t}$	0.098***	0.099***	0.178***	0.182***	0.053***	0.049***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.001)	(0.001)
$\text{GDPPC}_{c,t-5}$	-14.22***	-13.99***	-15.74***	-30.60***	17.49***	16.50***
	(0.731)	(0.739)	(1.466)	(1.213)	(0.606)	(0.613)
$\text{IndGrowth}_{c,t}$	-0.315	-0.315	-0.276**	-0.271**	-0.393***	-0.394***
	(0.076)	(0.076)	(0.150)	(0.148)	(0.073)	(0.073)
Constant	-147.9***	-176.4***	-346.1***	-582.6***	-63.81***	8.357*
	(9.149)	(11.92)	(16.08)	(16.51)	(3.768)	(4.483)
R-squared (within)	0.364	0.365	0.195	0.222	0.627	0.629
Corr(u_i)	-0.536	-0.531	-0.722	-0.775	-0.322	-0.304
Observations	323,252	323,252	147.933	147.933	175,319	175,319

Note: Standard errors are shown in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Table 4-3 shows the regression result for the relationship between core-technology competence and unrelated diversification. Columns (1) through (6), across the entire sample and two subsamples, report that the core-technology competence has positive and significant effect on the unrelated diversification of countries. This result implies that technological capability can be a factor to explain patterns of unrelated diversification of countries. Therefore, not only previous production experience can explain the path-dependent emergence of new industries in a country, but also technological experience can provide reasons of new addition to the export basket. The control variables show similar signs and significance with the result from **Table 4-1**, except for the negative and significant effect of industrial growth on the unrelated diversification in analyses with subsamples. The results seem obvious since the firms in the countries are likely to put their resources on the products in the growing industry, not unrelated specialization to another industry out of the growing industry.

To summarize, both the statistical evidence and econometric analysis support the hypothesis that technological capability of the country leads the future product diversification. More specifically, the technological capability stands behind the unrelated diversification, of which the driving factors have been less explained. The results show that the evolution of industrial structure is path-dependent to its technological structure, and current technological structure can help anticipating future industry emergence.

4.6 Conclusion

This chapter investigated the relationship between technological competence of a country and its effect on future diversification. The analysis differentiated the types of diversification into related and unrelated diversification, and tested whether technological competence act as a factor of diversification. The results support that countries with higher technological competence in their core technologies are more likely to diversify in the future. Specifically, current technological competence has positive and significant effect on unrelated diversification in the future.

As the results show, technological competence of a country has significant effect on diversification in the future. This relationship provides an empirical evidence to previous studies that consider technology as a key factor or resource in diversification, and suggests another way of interpreting unrelated diversification as a result of utilizing accumulated knowledge. By adding this novel empirical finding for linkage between technology and industrial diversification, the results provide implications for policies and theories on industrial diversification.

The results mainly lead to two theoretical implications. First, it emphasizes the role of technological capability of countries during industrial diversification. Although previous studies have considered technology as a key factor in product development (Abernathy & Utterback, 1978), not enough studies tried to figure out the direct relationship between technology and industrial diversification, especially at a national level. Considering the numerous policy efforts to create new industries in countries, it is meaningful to reemphasize the role of technology in industrial diversification and call for further studies on the relationship between the two. Second, only a few discussions studied the factors of unrelated diversification, mostly from excess financial resources or physical assets (Chatterjee & Wernerfelt, 1988). This study explains the unrelated diversification as a result of utilizing technological competence. Even though the unrelated diversification seems an irregular and unexpected diversification, it could still be the result of combination of current technological capability.

There are also implications to policy for strategic specialization and diversification. First, it is important to recognize the contribution to industrial diversification of technological competence in core technology fields. This suggests that countries should first understand where their current technological advantage is at when setting policy goals, and try to promote industries that are more closely connected with the technology fields they are capable of. This implication is more useful in recent industries where more products under different traditional industrial categories are based on similar technologies. Second, although less related with the current industrial structure, pursuing seemingly unrelated product or industry can be justified with the linkage with current technological structure. The results imply that countries should analyze their core technology fields first, rather than merely targeting an industry with a high potential to grow in the future. Patenting countries should utilize their current technological comparative advantage to find new industrial opportunities even if they are distant from the current industrial portfolio, and there are successful stories of firms' diversification that followed this argument. For example, Samsung successfully advanced into biopharmaceutical industry by utilizing its current technological capability accumulated from years of process innovation in electronics, and Fujifilm started its business in cosmetics and bio-healthcare industry based on its collagen processing technology from traditional film-making experience. Country-level policy should also seek for new industry opportunities that can best make use of what they already know, rather than what they have been doing.

These findings and implications call for further research. There are different types of relatedness measures, such as sharing the industrial classification codes, commonalities in inputs including knowledge flows (Pavitt, 1984; Scherer, 1982) or patent portfolios (Breschi et al., 2003; Jaffe, 1986), or co-occurrence of industries in a firm or country (Hidalgo et al., 2007; Teece et al., 1994). Confining the definition of related diversification only to diversification within the same classification may result in myopic or misconstrued approach to interpret diversification, considering that recent industries are more interdependent and overlapping with each other. Future studies with different relatedness measures from industrial and technological sides would add useful arguments to this discussion.

Moreover, export volume and patents may not represent the national competence on industrial performance or technology. Comparative advantage in export does not include the domestic production or consumption, and comparative advantage in USPTO patent does not include the domestic patents. These may have led to underestimating industrial diversification of countries that have higher dependence on their domestic markets, or have relatively more closed economies. Also, countries with fewer USPTO patents may also have been underestimated with their technological competence, since they could have more patent grants in EPO, JPO, or else. Further regional studies or country-level case studies with other datasets can resolve this issue.

Lastly, technological competence does not guarantee diversification or emergence of new industries. This study identifies technology as a key factor of diversification, but does not distinguish how diversification leads to diversification. Future studies would have to compare the different diversification patterns of countries that have similar technological competence, and identify why some countries diversify and some do not.

The results reconfirm the importance of technological competence as a key factor in diversification. They also suggest a multilateral viewpoint of path-dependence from not only the path of current industrial structure but also current technological level. Consequently, this chapter contributes to the understanding of path-dependence in emergence of new industries, and suggests technology as an alternative way to elucidate the starting point of unrelated diversification.

Chapter 5. Alternative Paths of Specialization for Developing Countries

5.1 Introduction

This chapter explores differences between the specialization options of developing countries and those of developed countries, and suggests that specialization policies should vary depending on countries' income levels. What and how much a country produces and exports are measures of its economic capability. Previous economic studies have sought to identify and emphasize what countries produce (Hausmann et al., 2007; Imbs & Wacziarg, 2003; Saviotti & Frenken, 2008), linking the current production structure with projected economic growth.

Ricardian theory on comparative advantage suggests that countries should follow comparative advantage when deciding what to produce. According to this theory, even the least developed country has comparative advantages in producing some products considering opportunity costs, and countries benefit from specializing in the products for which they have a comparative advantage. This logic became embedded in economic policy consultations, and many developing countries have received suggestions to focus on their current comparative advantage. Developing countries are generally more likely to have comparative advantages in labor-intensive products, benefitting from cheap labor costs. Therefore, developing countries would benefit from specializing in labor-intensive products or resource-intensive products that can best utilize their current capabilities.

Diversification and comparative advantage have been extensively studied, expanding the Ricardian theory. On top of the idea of export structures and the development paths of nations, Hidalgo et al. (2007) suggested a way to map what countries export. The authors illustrated a network space based on an export dataset, and explained why some countries take a longer period of time to advance to more sophisticated products. They argued that because of path-dependence, countries are less likely to advance to products that are distant from—or less related to—their current exports. Recently, more studies have focused on regional-level diversification (Boschma et al., 2013; Neffke et al., 2011), adding evidence to the argument that diversification paths depend on relatedness.

These studies have both contributed to theoretical discussions on path-dependence and been applied to actual policy in several countries. Some such policies were successful, and some were not (Rodrik, 2006). For example, the International Bank for Reconstruction and Development (IBRD) advised South Korea in the 1960s to focus on labor-intensive industries before moving on to more advanced sectors (Moon, 2016). Similar models were also suggested to African countries (Stein, 1992). More recently, a policy concept known as *smart specialization* was developed by the European Commissioner for Science and Research, to set an economic policy framework as part of the Europe 2020 strategy (Foray et al., 2012).

Regarding the implementation of smart specialization, scholars including Balland et al. (2018) have argued that complexity of knowledge and relatedness to current comparative advantage should be the primary factors in deciding specialization paths. A similar strategy was presented by Hausmann et al. (2014) using export data. Although these studies on specialization provide clear measures of complexity and relatedness to visualize the specialization paths of countries, they result in a pessimistic dilemma for developing countries. Specifically, many countries or regions may not have a 'smart' specialization path with both high complexity and high relatedness to the current production structure (Capello & Kroll, 2016; Grillitsch & Nilsson, 2015), because their industrial structure is labor-intensive and requires limited technology. Therefore, they face either a low-risk/low-return path with high-relatedness but low-complexity products, or a high-risk/high-return path with high complexity but low relatedness.

This study applies the recent specialization framework on developing countries, and makes two contributions to the recent discussion on smart specialization. First, the analysis herein points out the limitations of recent studies in providing practical implications for developing countries. The findings of this study provide support for the proposal that developing and developed countries face different specialization options. Second, it is argued that both production and knowledge capabilities should be considered simultaneously, because these capabilities have different effects on the future specialization of countries depending on income levels.

The rest of this chapter is structured as follows. Section 2 presents theoretical discussions on trade specialization and industrial development. Section 3 describes the data, and Section 4 explains the methodology of the analysis. Section 5 provides visualized evidence of specialization options for developing countries, along with econometric estimations. Section 6 concludes the chapter with a discussion of the implications and limitations of the study.

5.2 Previous literature

5.2.1 Studies on complexity and path-dependent specialization

What country produces represent the overall economic structure, and complexity of produced items can represent the economic complexity. In fact, high-income countries such as Japan and Germany are the major exporters of highly complex products such as machinery and chemicals. On the other hand, low-income countries are the major exporters of simple raw materials (Felipe et al., 2012). Producing complex products is directly related to the economy's level of development (Hartmann et al., 2017) and the reasons for being able to produce complex products have been a key question to economic studies.

The conventional approach to what countries produce and export focuses on fundamental aspects, such as physical and human capital, or the natural endowments of countries (Hausmann et al., 2007). These factors provide a framework for studying patterns of specialization, and countries are likely to follow their comparative advantages based on their endowments. The Heckscher-Ohlin-Samuelson (HOS) model suggests that comparative advantage is based on a comparison between resources of countries under different intensities of using different factors of production. The HOS model establishes a two-countries, two-goods, and two-factors model, where the two factors are labor and capital. The model predicts that when trading, a country will export goods that use the country's more abundant factor more intensively (Kim, 1995).

However, this approach assumes that the same technologies are present across countries, and does not consider the current industrial structure of countries. In reality, there is a wide variety of complexity across regions, and different degree of stickiness across knowledge (Balland & Rigby, 2017). Evolutionary economists have recognized the importance of the cumulative nature of capability, arguing that firms and countries are more likely to add on to what they already have been doing (Dosi et al., 1990; Nelson & Winter, 1982). According to evolutionary studies, countries are expected to seek new specialization opportunities in products similar to those that they are already producing. Therefore, the structural changes during specialization are not expected to be random, but instead are anticipated to be cumulative and dependent on what countries have done in the past (Hausmann & Klinger, 2007; Martin, 2010; Martin & Sunley, 2006). This tendency towards path-dependence discourages countries from deviating from their current export structure, and previses that high risks and costs come from deviation.

As a result, studies based on path-dependence have suggested more pessimistic prospects for developing countries. Hidalgo et al. (2007) proposed the concept of product space, which plots product classes on a network space map, illustrated based on the bilateral relatedness—or proximity—between products. In addition to the illustration of a general product space, the authors presented cases of South Korea and Chile as countries that reached different industrial structures—and therefore differences in national income levels—because of differences in their initial industrial structure. They argued that South Korea was able to advance into more complex and higher value-added industries such as machinery or automobiles as a result of starting from the steel industry, which was closely related to these complex industries. In contrast, Chile required more time to advance to complex products, because their initial industrial portfolio includes more simple products at the periphery of the product space. These case studies of two countries suggest that countries that have been exporting simple, less sophisticated products are unlikely to be able to advance to complex products. More recent studies have supported the path-dependence of evolutionary patterns on the product space (Boschma et al., 2013; Ferrarini & Scaramozzino, 2015; Romero et al., 2015), and confirmed the importance of initial economic complexity to future advancement in complexity.

Studies on specialization patterns based on relatedness have also presented practical implications. A recent study by Balland et al. (2018) suggested an interesting strategic framework for EU regions' smart specialization. The authors plotted possible specialization options by setting relatedness with the region's current knowledge base along the X-axis, while the complexity of technologies was on the Y-axis. In such a presentation, the specialization options at the top-right corner of the plot are low-risk (because the options are close to the current structure), high-benefit (because the options are more complex) opportunities. The results enable region-specific recommendations, because each region has a different knowledge base.

Path-dependence theory supports the idea that developing countries face more difficult circumstances in terms of specialization options, implying that different policy approaches should be deployed in developing countries. Advancing to new product or technology is difficult for any country, but considering invention as a recombinant search over interdependent knowledge (Fleming & Sorenson, 2001), upgrade in economic and technological complexity of a country would be more time-consuming and tedious to developing countries. The previous framework yields specific policy implications if a country has a comparative advantage in some area of complex knowledge or products, but if it does not, the framework faces a risk-return tradeoff that may not work well for less developed places (Muscio, Reid, & Leon, 2015; Percoco, 2013). For such countries, there is no 'smart' path of specialization that would combine low risk and high return, and therefore concerns have been raised regarding the usefulness of the smart specialization framework for less advanced regions (Foray, 2016). Thus, in order to apply this framework to developing countries with policy implications, additional studies should be conducted to fill the gap between the reality of developing countries and the content of theoretical frameworks.

5.2.2 Studies on industrial development and learning process

As discussed above, specialization patterns vary among countries according to their income levels. High-income countries with more complex industrial structures are likely to advance to new products in the product space (Boschma et al., 2013; Hidalgo et al., 2007), and in the knowledge space based on knowledge structure (Colombelli et al., 2014; Kogler et al., 2017). Although path-dependence is widespread in general, countries are likely to focus on less related products if they are at an intermediate level of economic development and have high levels of human capital (Pinheiro et al., 2018). This anomaly from path-dependence can make a difference in future economic growth, but only a few countries experience unrelated diversification.

Differences in specialization stem from differences in capabilities across countries, resulting in differences in subsequent processes of industrial development and learning. Industrial development and learning are inseparable (Balland & Rigby, 2017; Lall, 2000; Soete, 1985), and economic activities and paths of diversification depend on technical learning and knowledge (Feldman & Audretsch, 1999). More recent studies have also pointed out that successful learning from the production experience eventually leads to innovation (Berger, 2013; Locke & Wellhausen, 2014; Pisano & Shih, 2012). However, there are differences in learning-based specialization patterns depending on countries' income level. Whereas new products in developed countries emerge based on knowledge, and process innovation then follows (Abernathy & Utterback, 1978), production and process innovation take place first in developing countries. Through learning from the production experience, new technological capabilities gradually emerge afterwards (Kim, 1980; Lall, 1992). The concept of learning-by-doing (Cohen & Levinthal, 1990; G. Grossman & Helpman, 1990) also exemplifies the learning patterns of developing countries, and supports the proposal that the industrial development and learning patterns of developing countries are different from those of developed countries. Therefore, in order to analyze the specialization paths of countries, it is essential to study co-evolutionary learning patterns between production and technological capabilities.

From the previous discussion, two hypotheses arise regarding the specialization patterns of developing countries. First, lower-income countries are less likely to depend on their current knowledge structure during product diversification, because their knowledge base is comparatively weak and advancing to unrelated products involves risks. Second, lower-income countries are more likely to depend on their current production structure during technological diversification, because most of their learning comes from imitation of products and production experience.

5.3 Data

This study was primarily based on two datasets, respectively covering production and technological advantage. For measuring production advantage, international trade data from the UN Comtrade database were used, following the database construction process described by Hidalgo et al. (2007). An export dataset of standard international trade classification level 4 (SITC-4) revision 2 was constructed, covering 1980 to 2005. More up-to-date revisions have been published, through the revision 4 update in 2006, but revision 2 provides the export dataset with the longest duration of a consistent classification, meaning that it can show changes in exports within the same classifications for the longest period. The dataset combined data from two sources. Export data sorted by country of origin and destination through 2000 were obtained from the World Trade Flows (Feenstra et al., 2005), based on the UN Comtrade database. To this database, export data available at UN Comtrade were added, starting in 2001.

From the technological side, patent data from the Organization for Economic Co-operation and Development (OECD) Directorate for Science, Technology and Industry were used. OECD statistics (OECD.stat) provides patent data from the United States Patent and Trademark Office (USPTO) according to the applicant's residence, and gives the number of patents granted by countries. The number of patents granted is sorted by 4-digit International Patent Classification (IPC), and it includes patents for which there are multiple co-applicants from different countries.

Using the export and patent data as proxies of production and technological advantage has certain limitations. Export data cannot fully represent domestic production, since many countries' production activities result in domestic consumption. Export data cannot accurately show the production capability of countries, especially for countries with a large domestic market and a low export dependency. Additionally, the domestic patents of a country may better represent the knowledge sectors that have a technological advantage, especially if the country has fewer international patent data from USPTO. Sectoral differences can exist in the numbers of patents, since there are certain sectors where technological capability is tacit, or companies simply avoid frequent patent applications. Despite these possible systemic biases, patents can be particularly useful for analyzing international patterns of innovative activities and opportunities (Jaffe, 1986; Pavitt, 1985).

Because the export and patent datasets were based on the different classification systems of the SITC and IPC, respectively, it was necessary to adopt another methodology to link the two datasets by translating one to another. Algorithmic Link with Probabilities (ALP) concordance table linked the two, enabling the translation of data between SITC and IPC (Lybbert and Zolas, 2014). The authors constructed this concordance matrix based on data mining of more than 2 million patent abstracts and the titles included in the PATSTAT, and matching them with keywords of SITC and ISIC industry descriptions. This two-way crosswalk does not give the same result if applied backwards; specifically, the probabilistic linkage of SITC to IPC is different from that of IPC to SITC. In accordance with the export and patent data classifications of this study, linkage between 4-digit IPC and 4-digit SITC revision 2 codes was adopted for the analysis.

The linked export and patent data covered 84 countries and 784 product classes. These 84 countries had both export data from UN Comtrade and patent data from the OECD.stat. The countries were divided into four groups by their income levels in 2000: high (H), upper-middle (UM), lower-middle (LM), and low (L). The country classification followed the World Bank Analytical Classification. Since lower-middle and low-income countries had fewer patents granted, there is a limited number of lower-income countries for which patent analysis is possible. This study combined the 25 lower-middle and 10 low-income countries for a new group. As a result, the analysis uses three groups by countries' income levels during the analysis, with 29 high-income countries, 20 upper-middle-income countries, and 35 lower-middle and low-income countries.

5.4 Model

According to the classic economic theories on trade, a country can benefit from trading if it knows its current comparative advantages and specialize on them. One way to compare the comparative advantage of a country is calculating the revealed comparative advantage (RCA) of a country in that good. RCA measures whether a product's share of a country's export basket is larger than its share in the world market (Balassa, 1965). If the ratio is equal or larger than 1, the country has a comparative advantage in that product, and vice versa. This method is useful because it can capture specialization of each product, regardless whether the country has a large economy or not. The same measure can be used for technological advantage, for revealed technological advantage (RTA), if patent data is used instead of export data (Soete, 1987).

In order to analyze the specialization patterns of countries, Hausmann and Klinger (2006) suggests measuring the distance between products by the conditional probability of revealed comparative advantage. The authors measure the proximity between two products by probability of a country of having comparative advantage in one product given comparative advantage in another. If two products A and B are close, a country having advantage in exporting product A is likely to have advantage in exporting product B, and vice versa. Since the conditional probability is not a symmetric measure, the minimum of the pairs of conditional probabilities is calculated as proximity, expressed as:

$$\varphi_{p_1,p_2} = \min\{\mathrm{P}\left(\mathrm{RCA}x_{p_1} \geq 1 \middle| \mathrm{RCA}x_{p_2} \geq 1\right), \mathrm{P}\left(\mathrm{RCA}x_{p_2} \geq 1 \middle| \mathrm{RCA}x_{p_1} \geq 1\right)\} \cdots\cdots\cdots\cdots\cdots \quad (5\text{-}1)$$

Because proximity is a measurement between two products, it is possible to calculate proximity of a product with every other product. Calculation results in a matrix of 784 by 784, with the information of every proximity between every product, and a product space can be constructed. The product space shows the current export basket of a country, and also shows how much a product is close to the current export basket. The concept of density shows how the country's current export basket surround a particular product. Density is calculated by dividing the sum of all proximities between a product and other products with comparative advantage by sum of all proximity linked to that particular product. The calculation of density ω_{p_2} around product p_2 can be expressed as:

$$\omega_{p_2} = \sum_{p_1} x_{p_1} \phi_{p_1,p_2} / \sum_{p_1} \phi_{p_1,p_2} \cdots\cdots\cdots\cdots\cdots \quad (5\text{-}2)$$

Density shows how close a specialization option is from a country's export basket, but it does not show whether advancing to the option will be fruitful. Product complexity is a proxy for anticipating the future benefit from specialization by measuring the sophistication of the product. A product that is complex is probably produced by only a few countries with capability to produce a large variety of other products. Therefore, the complexity of a product can be measured through the ubiquity of the product and diversity of the countries that produce it.

Several researches have tried to calculate the Product Complexity Index (PCI) through this logic (Hidalgo & Hausmann, 2009; Hidalgo et al., 2007; Pinheiro et al., 2018). Defining M_{cp} as the matrix that is 1 if country *c* has comparative advantage in product *p* and 0 otherwise, diversity of a country is the number of products exported $(k_c = \sum_p M_{cp})$ and ubiquity of a product is the number of countries that have comparative advantage in exporting the product $(k_p = \sum_c M_{cp})$. Following previous studies, calculation of PCI along with the Economic Complexity Index (ECI) is iterated, which can be expressed as:

$$ECI_c = \frac{1}{k_c} \sum_p M_{cp} PCI_p$$

$$PCI_p = \frac{1}{k_p} \sum_c M_{cp} ECI_c \quad \cdots\cdots \quad (5\text{-}3)$$

Combining both equations, PCI can be computed as:

$$PCI_p = \sum_c \frac{M_{cp}}{k_p k_c} \sum_c M_{cp} PCI_p \quad \cdots\cdots \quad (5\text{-}4)$$

Following previous studies including Hidalgo et al. (2007), Boschma et al. (2013), and Colombelli et al. (2014), this study assumes that five-year time lag is reasonable for the economic structure to affect the emergence of new technologies, and the current knowledge structure to affect the emergence of new products. Also, in order to incorporate the data between the time lags, the average of three years was used for each year. For example, the average of 1999 through 2001 was used for year 2000.

The analysis includes two stages. First, framework for smart specialization (P. A. Balland et al., 2018) is applied to countries at different income levels. The framework is based on complexity and relatedness measures that vary across countries and change over time. The result shows how countries face different and dynamic specialization options.

Next stage gives econometric evidence to the effects of cumulated production capabilities on technological diversification, and cumulated technological capabilities on product diversification across different income level of countries. The econometric estimation can be expressed as follows:

$$\boldsymbol{RCA_{c,p,t+5} = \beta_1 RCA_{c,p,t} + \beta_2 ProdDensity_{p,t} + \beta_3 TechDensity_{p,t} + \Phi_c + \psi_p + \alpha_t + \varepsilon_{c,i,t}} \qquad (5\text{-}5)$$

$$\boldsymbol{RTA_{c,p,t+5} = \beta_1 RTA_{c,p,t} + \beta_2 ProdDensity_{p,t} + \beta_3 TechDensity_{p,t} + \Phi_c + \psi_p + \alpha_t + \varepsilon_{c,i,t}} \qquad (5\text{-}6)$$

where the dependent variable $RCA_{c,p,t+5}$ is 1 if the country *c* has RCA larger than 1 in product *p* at time *t+5*, and 0 if otherwise. Independent variable $RCA_{c,p,t}$ is 1 if the country *c* has RCA larger than 1 in product *p* at time *t*, and 0 if otherwise. In the same sense, $RTA_{c,p,t+5}$ and $RTA_{c,p,t}$ are 1 the country has RTA larger than 1 in product *p* at time *t+5* and *t*, and 0 if otherwise. $ProdDensity_{p,t}$ indicates the density of production capability around product *p* at time *t*, and $TechDensity_{p,t}$ indicates the density of technological capability via ALP concordance table around product *p* at time *t*.

The explanatory power of independent variables $ProdDensity_{p,t}$ and

$TechDensity_{p,t}$ is the key interest of the estimation. According to the previous discussion, countries at different income levels are expected to have different degree of path-dependence from their production and technological experience, so β_2 and β_3 will be different across countries. Following the previous studies with similar data structure (Colombelli et al., 2014; Neffke et al., 2011), the estimation of the equation is based on Ordinary Least Squares (OLS) model, and further tested by Generalized Linear Model (GLM) and probit model for improved efficiency in testing the binomial dependent variable.

5.5 Results

5.5.1 Ex-post application of specialization framework

Considering the path-dependence nature of specialization, it is necessary to identify the products with comparative advantage. The product space is useful to identify the current position of country on the product space map and tell whether it is on the periphery or on the core. However, the degree of relatedness of a product with the current export basket and potential benefit from advancing to the product are not visible in the product space. Hausmann et al. (2014) suggests a framework of an X-Y space to incorporate these two criteria to visualize the possible export options of specialization of a country. Average connectedness, measured by the average proximity of a country's products with all other products is defined along the X-axis. High relatedness refers to higher possibility to enter the product with relatively lower cost and risk, and vice versa. Product complexity, as a proxy for potential benefits of exporting a product is defined along the Y-axis. Addition of comparatively complex products to the export basket would increase the general complexity of the economy, and overall value of the exports. By mapping the products on the X-Y space, it is easy to see which possible specialization options have high relatedness to the current export basket, and at the same time high expected benefits. For the knowledge assets of countries, the same framework can be adopted. Balland et al. (2018) uses patent data and applies same framework for suggesting paths of smart specialization of EU regions, and divides the X-Y space into quadrants.

This framework intuitively suggests in which products a country would have to aim for. Clearly, the upper-right quadrant with higher relatedness and higher complexity (high-road) would be an advantageous choice than the lower-left quadrant with lower relatedness and lower complexity (dead-end). The upper-left quadrant with both high risks and high benefits (casino) and lower-right quadrant with both low risks and low benefits (slow-road) have risk-return tradeoffs (Balland et al., 2018).

This is a useful framework for countries with comparative advantages in a number of complex products, but many developing countries do not. They have advantages mostly in simple products compared with complex products. These countries, if plotted on the specialization framework, show most of their specialization options in the upper-left quadrant and lower-right quadrant. In other words, developing countries do not have a superior specialization option to another, but they only face a risk-return tradeoff. This points out the difference between specialization options of developing and developed countries under this framework, and shows a dynamic nature of specialization options.

This ex-post comparison of Korea and the United States in year 1970 clearly show that there are different specialization options between the two countries. As explained earlier, the X-axis represents average relatedness with other products and the Y-axis represents complexity of the product. Korea in 1970 was a developing country, with only around 5% of per capita GDP compared to that of the US. In **Figure 5-1**, whereas the US has ample specialization options that are both highly related to its industrial structure and highly complex, Korea has only two types of options of either casino on the bottom-right side, or slow-road on the top-left side. The slope of the regression line of two countries are diagonally opposite. This is sensible since in 1970, the Korean export basket was largely comprised of simple manufacturing products or raw materials, such as plywood and clothing. International research centers advised the Korean government at that time to take the slow-road and focus on the labor-intensive sectors first (Moon, 2016), because The technology-intensive sectors seemed to too apart from the Korean export basket.

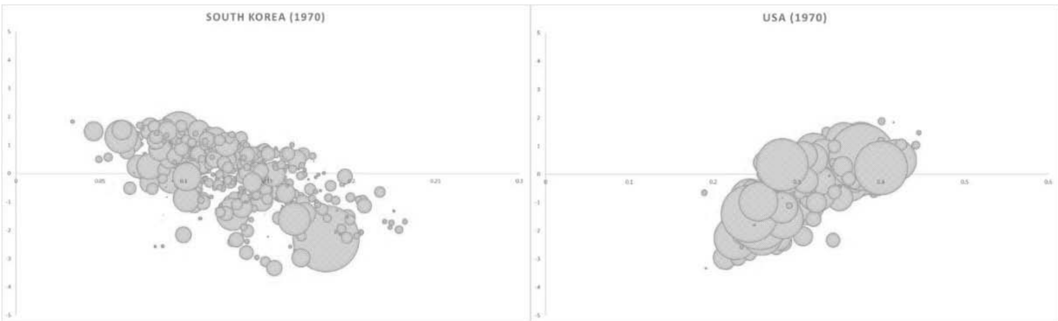


Figure 5-1. Application of the smart specialization framework to South Korea (Left) and the United States (Right) in 1970

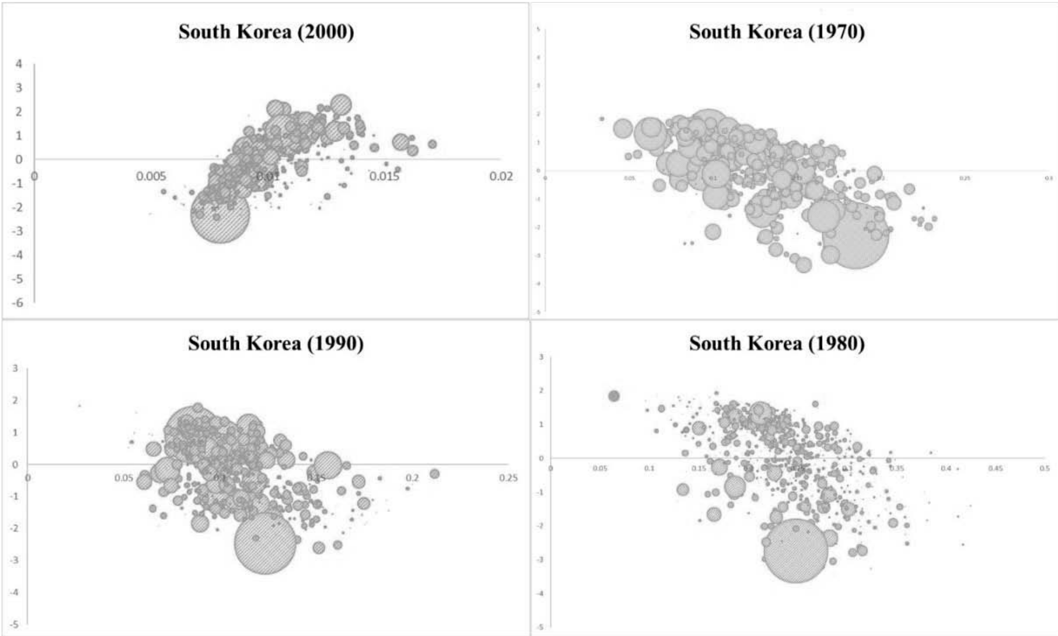


Figure 5-2. Application of the framework to South Korea, 1970-2000 (Clockwise, starting from upper-right)

The framework can also reflect that a developing country's specialization options can change dynamically across time, in addition to the comparison between specialization options of different countries at the same year. The relatedness to complex products is closely related to national-level capability, which is not static yet dynamic as it is in firm-level (Teece et al., 1997). Figure 5-2 shows the evolution of specialization options of Korea from 1970 to 2000. From the change in correlation between the relative density and complexity products, it is possible to see how Korean industrial structure underwent a transition to become closer to more complex products. The largest export in Korea in 1970 was plywood, with fabric clothes and knitted clothes following after, but in 2000, the largest exports were electronic microcircuits, automobile, and computer parts. The transition in complexity did not happen at once, but changed gradually. As the economy advanced in complexity, more complex options emerged nearby the current industrial structure. The slope of the regression line also changed from negative to positive.

The specialization framework not only shows an individual country's specialization options as most previous studies focused on, but also shows two important implications. First, the specialization options of developed and developing countries are different, so it is meaningful to distinguish countries at different income level during analyses. Second, the specialization options change over time, and studying the paths behind them would lead to specific implications for future specialization.

5.5.2 Empirical results

There are different specialization options of countries by their income levels, and likewise, there can be different factors that affect the specialization by countries' income levels. The following econometric analysis tests the path-dependence across the product space and the knowledge space. More specifically, the analysis examines whether the current production capability and technological capability affect the future production capability or technological capability, and how the relationship differ by countries' income levels. Five-year lags were taken during the analysis, so the base years are 1980 through 2000, and comparison years are 1985 through 2005. Key variables of interest are production density and technology density, each indicating whether the country has comparative advantage in production or knowledge in related products. From the first hypothesis, lower income countries are expected to show an insignificant relationship between current technological structure and future production. From the second hypothesis, lower income countries are expected to show a significant relationship between current production structure and future knowledge.

Table 5-1 shows the result of econometric analysis testing whether product density and technological density around a product class, along with the lagged dependent variable have positive effect on the comparative advantage in production. In all models of OLS, GLM, and probit, the results show the same patterns of relationship between the two densities at *t* and RCA at *t+5*. Columns (1), (4), and (7) show that in the high-income countries, lagged RCA, product density, and technology density have positive and significant effects on the dependent variable. The same results are observed in the upper-middle income countries, as shown in columns (2), (5), and (8). These results are consistent with previous studies that there exists persistence in the development of RCA, since development of industries is the result of accumulated capabilities (Boschma et al., 2013; Neffke et al., 2011; Pinheiro et al., 2018). Interestingly, lower-middle and low income countries show a different result from the other country groups. Although lagged RCA and product density have a significant and positive effect on RCA at *t+5*, technology density does not show a positive and significant effect across all models. Column (3) shows that only in the linear probability model, technology density is significant but negative, and in columns (6) and (9) with other models, technology density is not significant. The results show that having technological advantage in nearby products does not positively affect development of RCA in countries at lower income levels.

Table 5-1. Econometric estimation of production advantage to production and technological density, by income level of countries

Dependent variable	**Linear probability model**			**GLM**			**Probit**		
$RCA_{c,p,t+5}$	**High (1)**	**Up-Mid (2)**	**Low-Mid/ Low (3)**	**High (4)**	**Up-Mid (5)**	**Low-Mid/ Low (6)**	**High (7)**	**Up-Mid (8)**	**Low-Mid/ Low (9)**
$RCA_{c,p,t}$	0.621***	0.509***	0.436***	3.107***	2.523***	2.204***	1.623***	1.393***	1.203***
	(0.003)	(0.008)	(0.01)	(0.024)	(0.048)	(0.061)	(0.02)	(0.035)	(0.045)
$ProdDensity_{p,t}$	0.147***	0.347***	0.529***	1.028***	2.178***	3.04***	0.63***	1.41***	1.686***
	(0.009)	(0.03)	(0.038)	(0.069)	(0.199)	(0.241)	(0.046)	(0.129)	(0.17)
$TechDensity_{p,t}$	0.14***	0.156***	-0.066*	1.107***	1.093***	-0.35	0.672***	0.62***	-0.265
	(0.011)	(0.025)	(0.035)	(0.09)	(0.175)	(0.222)	(0.066)	(0.118)	(0.173)
Constant	0.014**	0.024**	0.082***	-2.848***	-2.66***	-2.232***	-1.693***	-1.609***	-1.394***
	(0.006)	(0.01)	(0.013)	(0.047)	(0.077)	(0.087)	(0.033)	(0.05)	(0.065)
R-squared	0.423	0.306	0.25						
Optimization				Maximum Likelihood	Maximum Likelihood	Maximum Likelihood			
(1/df) Pearson				1.005	1.000	0.998			
Log-likelihood							-24006.2	-5539.1	-3337.1
Observations	57,773	12,304	7,054	57,773	12,304	7,054	57,773	12,304	7,054

Note: Standard errors are shown in parentheses. * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Next analysis examines the factors of specialization in technology. **Table 5-2** shows whether product density, technological density, and the lagged dependent variable have positive effect on the comparative advantage in technology. In all models, high income and upper-middle income countries show the same results. Among the independent variables, only RTA at time *t* and technology density have positive and significant effects on RTA at time *t+5*. On the other side, product density is not significant or even negative. Similar with the previous analysis on the estimation of production advantage, lower-middle and low income countries show a different result from that of high or upper-middle income countries. Columns (3), (6), and (9) show that RTA at time *t* is positive and significant, but technology density is not significant. Rather, product density is positive and significant across all models.

These results confirm that there exists a strong path dependence in specialization of both production and knowledge, since having comparative advantage in the previous time period increases the probability of having comparative advantage in the next period. Furthermore, countries tend to develop comparative advantage in products that are related to their current production or knowledge structures. However, countries at different income levels experience different factors leading to specialization. Lower income countries tend to depend on their product relatedness rather than knowledge relatedness during technology specialization, and does not depend on knowledge relatedness during product specialization, whereas higher income countries depend on knowledge relatedness during technology specialization and both product and knowledge relatedness during product specialization.

Table 5-2. Econometric estimation of technological advantage to production and technological density, by income level of countries

Dependent variable	Linear probability model			GLM			Probit		
$RTA_{c,p,t+5}$	High (1)	Up-Mid (2)	Low-Mid/ Low (3)	High (4)	Up-Mid (5)	Low-Mid/ Low (6)	High (7)	Up-Mid (8)	Low-Mid/ Low (9)
$RTA_{c,p,t}$	0.461***	0.345***	0.364***	2.027***	1.489***	1.532***	0.353***	0.501***	0.95***
	(0.004)	(0.009)	(0.011)	(0.02)	(0.041)	(0.052)	(0.029)	(0.051)	(0.031)
$ProdDensity_{p,t}$	-0.000	0.046	0.086*	-0.002	0.209	0.397*	-0.161***	0.24*	0.24*
	(0.010)	(0.035)	(0.045)	(0.059)	(0.17)	(0.208)	(0.046)	(0.123)	(0.126)
$TechDensity_{p,t}$	0.434***	0.626***	-0.057	2.332***	3.043***	-0.265	2.261***	2.297***	-0.159
	(0.015)	(0.032)	(0.041)	(0.081)	(0.158)	(0.191)	(0.085)	(0.133)	(0.116)
Constant	0.079***	0.135***	0.335***	-2.04***	-1.675***	-0.686***	-1.13***	-0.951**	-0.427***
	(0.007)	(0.012)	(0.016)	(0.038)	(0.061)	(0.072)	(0.038)	(0.048)	(0.043)
R-squared	0.267	0.191	0.133						
Optimization				Maximum Likelihood	Maximum Likelihood	Maximum Likelihood			
(1/df) Pearson				0.999	0.997	1.001			
Log-likelihood							-31177.9	-7214.3	-4394.9
Observations	57,773	12,304	7,054	57,773	12,304	7,054	57,773	12,304	7,054

Note: Standard errors are shown in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

5.6 Conclusion

In evolutionary studies, changes in technologies and economic structures are considered as a cumulative process, and therefore are seen as closely constrained by what actors have done in the past (Dosi et al., 1990). The empirical evidence from this study reconfirms the path-dependence during specialization and complexity development of a country. Despite certain counterexamples, such as Korea that transformed its industrial structure quickly to make its economy more complex, countries are likely to add new products to their export basket if the products are similar to what they have been exporting. This is also in line with the neoclassical viewpoint of trade specialization, in that patterns of specialization become entrenched over time, as explained by economies of scale (Krugman, 1987a). In addition to supporting the path-dependence theory, this study suggests that future frameworks for specialization should acknowledge the different backgrounds of countries in terms of their income or economic complexity.

This chapter has demonstrated that specialization patterns of countries are path-dependent, but differ in specialization options and patterns according to their income level, which is closely related to their level of economic complexity. Developing countries tend to rely more on their export structure, but less so on knowledge structure, during product specialization. Furthermore, their knowledge specialization is more heavily influenced by what they export than by what they know. Developed countries experience knowledge specialization based on their knowledge structure. This is in line with the argument of Martin and Pavitt (1992) that in the early stages of development, factor endowments influence the accumulation of technology, while in later stages technological knowledge can be reflected in comparative advantages of production.

These findings suggest that studies on specialization and complexity based on path-dependence theory should also include perspectives involving production and knowledge capabilities, along with the economic complexity of countries. More specifically, relatedness to a complex product or knowledge should involve both production and knowledge structures of a country. Recent studies have suggested that there is a close relationship between production sites and knowledge development, since production sites provide hands-on experience for new ideas and work as testbeds for innovative concepts (Berger, 2013; Locke & Wellhausen, 2014). This relationship is persistent both in national-level studies and in firm-level analyses (Dosi et al., 2017).

In line with the theoretical implications outlined above, this study yields different policy implications depending on the income level of countries that try to initiate specialization policy in products or knowledge. Specialization strategies must rely on relatedness to the current capabilities, in order to discover which options would be beneficial (Balland et al., 2018). Specifically, knowledge specialization of developing countries that lack a strong initial knowledge structure should be in line with their industrial structure, and policies should encourage learning-by-doing. In measuring the distance from a complex knowledge, production capability should be taken into account, especially for developing countries. Therefore, a country with lower-middle income level that has a comparative advantage in producing automobiles, such as Indonesia, should invest on research and development towards the technologies related to automobiles, such as internal combustion. A country with strong production capability in steel production should focus on accumulation of knowledge in steel and metallurgy. On the other hand, a country at higher-income level should diversify based on its technological capabilities, as mentioned in previous studies in European regions (Kogler et al., 2017; Pinheiro et al., 2018) and US regions (Boschma et al., 2015; Kogler et al., 2013). Furthermore, the close linkage between comparative advantage in production and knowledge generation emphasizes the importance of co-location of research and development with manufacturing (Bathelt et al., 2011; Buciuni & Finotto, 2016). Establishing an innovative cluster can help absorbing tacit knowledge during early stages of the industry life cycle (Audretsch & Feldman, 1996), especially for developing countries aiming to learn from producing complex products and upgrade their economic complexity.

These findings and implications suggest further research directions. This study does not differentiate among industries, although each industry can have different specialization patterns depending on their industry-specific characteristics (Heimeriks & Balland, 2016). Developing and developed countries have comparative advantages in specific industries, which may have other differences, in addition to variation in the level of complexity. These differences are not represented in relatedness measures, such as capital intensiveness, degree of tacit knowledge, or ubiquity in other countries, but can lead to differences in the risk or time for specialization. Furthermore, each industry in each country can have a unique path to specialization due to country-level factors, such as a neighboring country already producing that product (Bahar et al., 2014), differences in institutions (Boschma & Capone, 2015) and differences in extra-regional linkages (Zhu et al., 2017). Future studies incorporating differences among industries would be able to assess the risks and benefits of certain specialization strategies in detail.

Additionally, further studies should explore comparative advantage in greater depth, since the binomial measure of comparative advantage is limited in explaining quality upgrading or improvements in value-added. This study focuses on whether countries have a comparative advantage or disadvantage, assuming that a comparative advantage is equivalent, as long as the share of the product in the country is larger than the product's share in the world. However, there can be different degrees of comparative advantage, which may eventually lead to different possibility of advancing to related products.

Lastly, the factors that cause the path-dependence between the two spaces of production and knowledge are still unexplained. Some previous studies have considered manufacturing capability as an innovation capability (Binz & Anadon, 2018; Guan & Ma, 2003), and the concept of learning-by-doing postulates a linkage between production and knowledge, but the cause-and-effect relationship remains unclear. Further research on preconditions or reasons for path-dependence across the product and knowledge spaces will lead to practical innovation policies closely linked with production capability. The cause-and-effect between the different economic development levels and diversification patterns should also be analyzed further. Countries at lower-income levels could have shown a production-based knowledge diversification, possibly because of insufficient resource to research and development, and vice versa for countries at higher-income levels. The same limitation is present in the case of industrial diversification, where countries at lower-income levels depended heavily on their previous production experience only. Therefore, a future study based on countries that have experienced notable economic growth or change in industrial structure can include an event analysis, to figure out the factors leading to different diversification paths. The cause-and-effect between the different economic development levels and diversification patterns should also be analyzed further. Countries at lower-income levels could have shown a production-based knowledge diversification, possibly because of insufficient resource to research and development, and vice versa for countries at higher-income levels. The same limitation is present in the case of industrial diversification, where countries at lower-income levels depended heavily on their previous production experience only. Therefore, a future study based on countries that have experienced notable economic growth or change in industrial structure can include an event analysis, to figure out the factors leading to different diversification paths.

Chapter 6. Conclusion

6.1 Summary of the study

The mainstream literatures on economic growth have mostly focused on finding the causes or factors of economic growth regardless of the current industrial structure or stage of economic development. Evolutionary economics or neo-Schumpeterian studies on the other side approached the topic of economic development from absorptive capacity and dynamic capabilities, and other heterogeneous characteristics of countries, yet mostly based on qualitative analyses. In order to fill this academic gap, this study emphasizes the different capabilities of countries at different development stages and economic complexity, and identifies jumps and traps during the advances in stages. This study has its uniqueness in interpreting the economic complexification in multilateral stages of production and technological capability accumulation. In addition to the industrial and technological path-dependence literatures focusing on a single capability, this study suggest that production and technological capability can be a factor to emergence of each other, and the influence to each other can vary across different stages of economic development. One chapter on theoretical framework and three chapters on empirical evidence on the relationship between the two capabilities have added a co-evolutionary perspective in interpreting economic complexification from the capability-based viewpoint.

Chapter 2 sets a framework to studies the jumps and traps that a country faces during its industrial development, and suggests that the country evolves through three stages of co-evolution of production and technological capability. This chapter was motivated by the gap between evolutionary studies that emphasized the importance of technological capability and heterogeneous characteristics of countries, and more recent path-dependent studies on economic complexification that focus on the current capability and industrial structures. The framework depicts the co-evolution process by an interconnected network space of product space and technology space, and suggests that the process inevitably involves frequent jumps and traps during economic diversification and complexification. Korean economic development case, as an example of a country that went across these stages recently, supports the argument and suggests a successful path of diversification. In addition to suggesting a framework to understand the development paths of countries from capability-based viewpoint, this chapter highlights the importance of further studies on the relationship between production and innovation.

Chapter 3 studies the relationship between the current production capabilities and emergence of new technological capabilities at the national level. The main hypothesis is that production experience in similar products helps acquiring technological advantage through the learning from the production experience. By integrating two network spaces of product space built on the export data and technology space built on the international patent data by the ALP concordance matrix, the analysis tests the relationship across 93 countries from 1980 through 2005. The results support that the past production advantages positively and significantly influences the emergence of new technological advantages, especially in proximal products. This finding enriches the previous path-dependence studies, and provides an empirical evidence to consider production as a key driver to innovation.

Chapter 4 presents the role of core-technology competence of countries in change in degree of industrial diversification. By using international export and patent data, this study focuses on countries with patenting experience and how the technological capability leads to diversification. Specifically, it focuses on unrelated diversification and considers the technological competence as a key factor. This chapter expands the previous firm-level studies on resource-based diversification into national-level, capability-based diversification. By using both export and patent data from 1980 through 2010, the analysis supports that the current technological competence in core technologies positively influences the change in degree of industrial diversification, and specifically unrelated diversification. These findings suggest that technological capability can provide a path to path-dependent industrial diversification process, and explain the unrelated diversification by path-dependence.

Chapter 5 examines the different relationship between the production capability and technological capability across different stages of economic development. Specifically, it analyses how the current production and technological capabilities affect the future capabilities from path-dependent point of view. The findings show that there exist different patterns of relationship between the two capabilities, and complement the limitations of previous studies on specialization patterns of countries with a cure-all policy implication. For lower-income countries with lower capabilities in technology or production, their strategy to promote both innovation and industrial development should be focusing on their current production advantage. On the other hand, the current technological capability has significant effect on future production and technological capability in higher income countries. It is notable that the technological capability in the future is closely related with the current production capability in developing countries, whereas it is more connected with the current technological capability in richer countries. This study suggests that a multilateral path between product space and knowledge space exists, and studies on path-dependence should consider both factors in anticipating future emergence in products or technologies. The results from panel data analysis across 35 years and 84countries lead to different prescriptions to countries at different income levels. In conclusion, specialization policies of developing countries should focus on their comparative advantage in production, and those of developed countries should focus on their comparative advantage in technology.

In conclusion, the chapters in this study argue that production and technological capabilities are not only closely linked with each other, but dynamically affects each other through co-evolution. Empirical evidence in three chapters clarify the relationship; production experience in similar products leads to emergence in technological advantage, technological capability leads to higher possibility of new industry emergence, and the different relationships of the two capabilities across different stages of economic development. These results provide a unique policy implication that countries should refer to both current production and technological capability in order to succeed in strategic technological and industrial diversification, respectively

6.2 Implications

6.2.1 Implications for theory

In evolutionary studies, changes in technologies and economic structures are considered as a cumulative process, and therefore are seen as closely constrained by what actors have done in the past (Dosi et al., 1990). The empirical evidence from this study reconfirms the path-dependence during specialization and complexity development of a country. Despite certain counterexamples, such as Korea that transformed its industrial structure quickly to make its economy more complex, countries are likely to add new products to their export basket if the products are similar to what they have been exporting. This is also in line with the neoclassical viewpoint of trade specialization, in that patterns of specialization become entrenched over time, as explained by economies of scale (Krugman, 1987b). In addition to supporting the path-dependence theory, this study suggests that future frameworks for specialization should acknowledge the different backgrounds of countries in terms of their income or economic complexity.

As Rosenberg (1982) stated "learning consists of increasing skill in production," classic studies on innovation have continuously discussed the role of production in promoting innovation. However recently, there have been innovation policies that locate production far from where innovation is born. Also recently, there were only a few discussions on the linkage between production and innovation, such as scholars including Pisano and Shih

(2012) who refuted these policies arguing that innovation is the result of the link between research and development and manufacturing. Innovation is the time-consuming result of transfer of learning between production and new ideas. Therefore, innovation studies on technological path-dependence need to expand their discussion to include the linkage between production and innovation, and provide empirical evidence to the linkage.

In addition to supporting previous studies that suggest persistence of technological capability, the results suggest that diversification of technological capability of countries is dependent upon production activities accumulated over time. Current technological path-dependence theories cannot explain big jumps on technology space, or in other words, emergence of technological advantage in technologies that are relatively distant from current set of technological capability. Findings of this study suggest an alternative path to future innovation, stemming from the current set of production capability. Countries are likely to achieve technological advance if they already have hands-on experience to produce similar products. Evolution paths of technological landscape are paved by not only research experience, but also by production experience.

6.2.2 Implications for practice

In line with the theoretical implications outlined above, this study yields different policy implications depending on the income level of countries that try to initiate specialization policy in products or knowledge. The results give strong implications for national-level innovation policies, in re-emphasizing the importance of production advantages.

First, countries seeking advance to new technological capabilities should consider not only their current technological advantages, but also their production advantages. Specialization strategies must rely on relatedness to the current capabilities, in order to discover which options would be beneficial (Balland et al., 2018). Targeting a distant technology should recognize that it involves numerous steps of technological evolution considering the sticky nature or knowledge (von Hippel, 1994), and takes even more time if the country does not have production capability to facilitate testing the new technologies in markets. Close analysis of current comparative advantage in production should be the basis of technological specialization, and technological diversification plan should be close to a country's position on product landscape. In addition to the analysis of current production capability, future innovation policies should include promotion of linkage between production sites and research activities.

Second, efforts to foster production capability in related products of targeted technology should be considered as an option of innovation policies. Specifically, knowledge specialization of developing countries that lack a strong initial knowledge structure should be in line with their industrial structure, and policies should encourage learning-by-doing. In measuring the distance from a complex knowledge, production capability should be taken into account, especially for developing countries. Producing new products inevitably accompanies importing and imitating technologies from other countries, and this is an essential step to countries that do not have advantage in related technologies. To these countries, promoting research and development is important, but production can lead to as much advance in technological capability.

Third, innovation policies should be coherent with economic policies, and policymakers should encourage active convergence between industry and research (Hemmert et al., 2014). Understanding the production environment can lead to design capability, and co-locating research and development with production helps engineers to find and fix the problems (Pisano and Shih, 2012), even within the low-tech industries (Buciuni & Finotto, 2016). The close linkage between comparative advantage in production and knowledge generation emphasizes the importance of co-location of research and development with manufacturing (Bathelt et al., 2011; Buciuni & Finotto, 2016). Establishing an innovative cluster can help absorbing tacit knowledge during early stages of the industry life cycle (Audretsch & Feldman, 1996), especially for developing countries aiming to learn from producing complex products and upgrade their economic complexity. Innovation policies should take a further step to closely study the link between production and technology, and emphasize on the coevolution of production and technological capabilities.

6.3 Limitations and direction for future research

These findings and implications call for further research. This study does not differentiate between each product and industry, and considers every product identically. The diversification pattern and degree of influence of production capability on technology emergence may differ according to the complexity of products and industries. Although the analyses are at product and technology levels, the implications are towards the countries and do not give product-specific or technology-specific policy suggestions. Future research would have to find different patterns of technology emergence in traditional industries or high-tech industries, in order to give closer implications to countries with different industrial structures. Specifically, there can be different speeds of innovation and different forms of production-innovation linkages across industries. In relatively traditional, labor-intensive industries with more tacit knowledge required, the knowledge accumulation from production experience can take longer time. On the other hand, more recent industries, or industries with ample codified knowledge can expect a faster learning from production. Considering the rapidly advancing technologies of ICT society, future studies on more recent industries would bring better insights by assuming smaller time gap between production and innovation or different time lags by sectors. For example, in certain industries, such as software service industry, require dynamic analyses reflecting rapidly changing network positions (Kim et al., 2015) and consider the role of customers and third-party actors on innovation (Baek et al., 2014). Similarly, diversification pattern could be different by degree of complexity of technologies, too. Further research based on this study can bring policy implications by investigating whether influence of production experience is larger in more complex products or technologies, or in simpler products or technologies.

Additionally, further studies should explore comparative advantage in greater depth, since the binomial measure of comparative advantage is limited in explaining quality upgrading or improvements in value-added. This study focuses on whether countries have a comparative advantage or disadvantage, assuming that a comparative advantage is equivalent, as long as the share of the product in the country is larger than the product's share in the world. However, there can be different degrees of comparative advantage, which may eventually lead to different possibility of advancing to related products. The current measure of RCA or RTA has limitations in indicating the degree of comparative advantage across different countries, or across the time periods for changing comparative advantage. Therefore, alternative measures should be included for comparison or keeping track of growth rate for comparative advantage. However, only a limited number of previous studies use the modified RCA measures such as MRCA or RSCA (Laursen, 2015; Welfens & Perret, 2010), and further studies should bridge the gap of this methodological limitation.

Lastly, the factors that cause the path-dependence between the two spaces of production and knowledge are still unexplained. Production itself may not automatically lead to innovation, and vice versa. Some previous studies have considered manufacturing capability as an innovation capability (Binz & Anadon, 2018; Guan & Ma, 2003), and the concept of learning-by-doing postulates a linkage between production and knowledge, but the cause-and-effect relationship remains unclear. The results supported that production experience has a significant influence on emergence of technological capability, yet did not confirm whether this relationship is universal or occasional. There may be preconditions to spurring innovation through production activities, and differences among forms of productions which will bring different impacts on innovation (Hansen and Ockwell, 2014). Even if a country produces automobiles or electronics, yet operates only simple assembly under a subcontract from a technologically advanced country, production will not guarantee emergence of automobiles or electronics technology. Therefore, a closer look on countries' production under value chain would bring additional explanation for the different paths of technological advance between countries with similar industrial structure. Future studies would have to closely compare countries with different innovation paths despite similar production experiences, and figure out under which circumstances production would lead to innovation and vice versa. Further research on preconditions or reasons for path-dependence across the product and knowledge spaces will lead to practical innovation policies closely linked with production capability.

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Abstract (Korean)

경제 개발에 대한 연구는 기술 혁신을 노동력 증가 및 자본금 축적과 같은 전통적인 요소와 함께 경제 성장의 주요 요소로 인식하고 있다. 보다 최근의 연구는 국가의 산업 구조의 복잡성 차이가 경제 성장 패턴에 미치는 영향에 더 중점을 두었다. 기술 혁신이나 산업 구조에 중점을 둔 이전의 연구는 생산과 혁신의 경계를 종종 모호하게 다루고 있지만, 생산과 혁신의 중요성과 서로의 상호 의존성을 암묵적으로 인정하고 있다. 그러나 지금까지 생산과 혁신의 두 요소를 명시적으로 연결시키는 연구는 부족하였다.

본 연구는 경제 복잡화 또는 산업 개발이 순조롭고 부드럽게 이루어지는 전환 과정이 아니라, 생산 및 기술 역량의 축적 및 다각화 과정에서 몇 가지 함정과 이를 뛰어넘는 도약을 포함한다는 가설로 시작한다. 나아가 본 연구는 국가의 생산 역량과 기술 역량 간의 경로 의존적 패턴을 식별하고 기존의 연구에 다차원적 역량 관점을 제공하는 것을 목표로 한다. 이를 위해 이하의 장은 국제 수출 및 특허 데이터를 기반으로 한 제품 공간과 기술 공간을 바탕으로 진화론적 관점에서 경제적 복잡성 문제를 접근한다.

2장ㅇ은 산업 발전 과정에서 한 국가가 직면하는 도약과 함정을 제시하고, 진화론적 관점에서 국가의 성장 단계를 이해하기 위한 프레임워크를 설정하였다. 특히 이 장은 밀접하게 연결된 생산과 지식 사이의 3단계의 공진화를 통해 성공적인 국가가 진화한다고 주장한다. 이러한 공진화 단계에는 국가의 비

교 우위를 따라가는 부드러운 경제구조의 전환이 아닌 빈번한 도약 및 함정이 산업 다각화 과정에서 발생한다. 이 연구에서는 제품 공간과 기술 공간 사이의 연결을 통한 분석을 통해 생산 능력과 지식 능력의 공진화 경로를 보여준다. 이 연구에서 제안하는 공진화 단계를 지난 수십 년 간의 한국의 개발 경험의 사례에 비추어볼 때, 경제 발전 중 국가가 마주하는 도약의 기회와 함정을 식별하여 성공적인 국가 발전을 이루기 위해 취해야 하는 다각화 경로를 제시한다.

3장은 생산 역량이 국가 차원에서 새로운 기술 역량의 발전을 촉발했는지 여부를 연구하였다. 이 장에서는 네트워크 분석을 위한 '제품 공간' 및 '기술 공간' 개념을 채택하고 현재 생산 역량이 연관된 기술의 미래 기술 역량에 영향을 미치는지 분석한다. 이를 위해 1980년부터 2005년까지의 수출 데이터 및 국제 특허 데이터와 생산 및 혁신을 연결하는 ALP (Algorithmic Links with Probabilities) 연계표를 기반으로 국가 간 비교 분석을 진행한다. 분석 결과, 국가의 과거 생산 우위가 새로운 기술 우위의 출현에 중요한 역할을 한다는 것을 확인하였다. 이 결과는 현재의 생산 역량이 신산업의 발현뿐만 아니라 기술 혁신과 기술 역량 발현에도 진화 경로의 역할을 맡는다는 것을 시사한다.

4장은 국가 별 산업 다각화 패턴과 국가의 핵심 기술 역량 간의 관계를 살펴보았다. 여기서 수출 구조의 변화에 의해 측정된 산업 다각화는 국가가 하고 있는 것을 나타내고, 특허 구조에 의해 측정된 지식 또는 기술 역량은 국가가 알고 있는 것을 나타낸다. 기업 동학 이론의 기존 연구에서 둘 간의 관계를 규명하였으며, 이 장은 이전 기업 차원의 다각화 연구를 생산 및 기술

역량의 국가 차원의 공진화 과정으로 확장시킨다. 이 장에서는 1980년부터 2010년까지 ALP 연계표에 의해 연결된 국제 수출 및 특허 데이터를 사용한다. 분석 결과, 미래의 산업 다각화 정도의 변화는 현재의 기술 역량과 양의 관계가 있으며, 특히 기술 역량은 미래 비연관다각화의 바탕이 된다는 점을 확인하였다. 이러한 연구 결과는 산업 다각화에서 기술 역량의 중요성을 제시한 이전 연구를 뒷받침하고, 기술 역량을 비연관다각화의 핵심 요소로 고려하여 해석하는 새로운 관점을 제안한다.

5장은 국가의 수출 구조 변화를 분석하여 역량과 경제 복잡성의 발전 유형을 국가가 특화 과정에서 마주하는 선택지와 함께 분석하였다. 이 장에서는 여러 경제 단계에서 국가의 특화 선택지를 대조하고 수년에 걸친 산업 구조와 지식 구조의 동적 변화 양상을 제시하였다. 분석 결과, 개발 도상국에는 복잡성이 높고 동시에 현재 생산 구조와의 유사성이 높은 목표 산업이 존재하지 않기 때문에, 국가의 특화 패턴에 대한 현재 연구의 정책적 시사점이 적용되지 않을 수 있음을 보여준다. 결과적으로 개발 도상국은 '고위험 고수익' 또는 '저위험 저수익'의 전략을 취할 수 있지만 기존 연구가 선진국에게 처방전으로 내놓는 '저위험 고수익' 전략은 선택할 수 없다. 이를 보완하기 위해, 이 장은 특화 과정의 경로의존성을 이해할 수 있는 제품 공간과 기술 공간 사이의 다자간 경로를 제안한다. 국가 단위의 비교 분석에 따르면, 새로운 역량 발전에 대한 현재 생산 및 지식 역량의 영향은 국가의 소득 수준에 따라 다르다는 것을 시사한다. 연구 결과는 국가의 복잡성 발전을 위해서는 생산 및 지식 구조에 대한 이해가 동시에 필요하며, 국가의 발전 수준에 따라 다른 전략이 필요

하다는 정책적 시사점을 제공한다.

연구의 결과를 종합하면, 본 연구의 주된 의미는 생산과 기술 역량이 상호 의존적이며 경제가 복잡해짐에 따라 함께 발전한다는 것이다. 이 결과는 기술 역량이 산업 다각화 패턴을 설명하는 데 없어서는 안될 요소이며, 생산 역량이 기술 혁신을 촉진한다는 주장을 뒷받침한다. 특히, 생산과 기술 역량은 국가의 소득 수준에 따라 서로에게 다른 영향을 미치는 패턴을 보여준다. 이러한 연구 결과를 바탕으로, 본 연구는 현재의 생산 및 기술 역량이 각각 전략적 기술 및 산업 다각화에 대한 주요 지침이 되어야 한다는 새로운 정책적 관점을 제공한다.

주요어 : 경제 복잡성; 다각화; 경로 의존성; 역량; 비교 우위; 제품 공간
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