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Evolutionary Economic Geography, Industrial Symbiosis, and Green Growth-Oriented Processes

-A small-scale study of petrochemical firms in Korea’s Ulsan-Mipo National Industrial Complex-

진화경제지리학, 산업공생 및 녹색성장지향적 과정

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Abstract

Environmental concerns, especially over climate change resulted from global warming, have increased in severity, ushering in demand for a new way forward that orients economies toward sustainable paths. Green growth has been garnering increasing attention in this regard as it is an alternative model that is able to accomplish both economic growth and environmental sustainability at the same time.

The present research explores processes of green growth and industrial symbiosis in Korea from the perspective of Evolutionary Economic Geography (EEG). To be more specific, the present research explores concepts central to EEG theory such as path-dependence, creation, and diversification, in addition to institutional and policy considerations, vis-à-vis evolutionary processes related to green growth-oriented activity of petrochemical firms in the Ulsan-Mipo National Industrial Complex (UMNIC). Industrial symbiosis is of particular interest given its focus on resource sharing, which is central to green growth strategies.

After reviewing the existing literature with respect to EEG, industrial symbiosis, and the petrochemical industry, the present research sets up three research questions (one with multiple parts) deployed to examine multi-actor and multi-spatial evolutionary processes of path development in the UMNIC, and to concurrently apply an EEG perspective to industrial symbiosis considerations.

Data were acquired via an electronic questionnaire distribution that took place from October 27, 2020 to November 16, 2020. Environmentally-related technology specialists or senior managers of the petrochemical firms in the UMNIC

served as firm respondents. The methodology deployed is primarily quantitative, using descriptive statistics and non-parametric Mann-Whitney U tests and Kendall's Tau B tests. Data reliability is assured via Chronbach's Alpha.

The research results reveal that green evolutionary processes take place in the UMNIC in several dimensions. First, the petrochemical firms have created new paths with new knowledge supplied through external networks. Second, new knowledge is also shown to be a trigger for path diversification as it is combined with existing intra-firm resources. Third, because the petrochemical industry reflects the characteristics of a mature industry, the petrochemical firms in the complex have technological lock-in, which in turn makes them somewhat dependent on the current industrial ecosystem. In contrast to standing EEG theory, spin offs have not been integral to green growth-related outcomes.

In addition to the evolution of multiple means of path development, the present research confirms that the formation of industrial symbiosis, much as with path development processes described above, is attributed to networks with other actors, especially knowledge suppliers such as research institutions. While acknowledging that government support is integral to their green growth-related efforts, firms nonetheless related that inefficient government administration services pose the largest liability to their green growth-oriented business activity. Institutional endowments, for example rules and cultural norms, are acknowledged by firms as important to their green growth-oriented, industrial symbiotic relationships and activity.

The present research attempts to bridge academic gaps in two senses. First, by paying attention to firm evolution, this research tries to overcome a perceived limitation of EEG, namely that descriptions of the major economic agents

following regional economic development paths are vague. One result, for example, is that inter-regional industrial symbiosis is firm-centric, while extra-regional connections are more likely state facilitated. Second, this research offers insight into green growth in Korea which can be used to augment the majority of studies that overwhelmingly focus on the political dimension. For example, given the environmental challenges of the times, results suggest that firms may be contributing more toward green growth via green innovation capability intensification, environmental purification, environmental education, and the purchase of environmentally-friendly raw materials, all of which transcend legal-based supply chain considerations.

Keyword: Evolutionary Economic Geography, Green growth, Industrial symbiosis, Path creation, Path dependence, Path diversification

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1. Introduction

1.1 Research Relevance

During a New Year Special Speech delivered on January 3rd, 2011, South Korea's (Korea from here on) former President Lee stated that Korea was the first nation to have enacted a Framework Act on Green Growth. In addition to this speech, the country's current President, Moon, also made an announcement about a Korean Green New Deal, expressing hope that this strategy would help to restructure the Korean economy to counteract the recession brought on in large part by COVID-19 (Lee, Sung, & Choi, 2020).

The Green New Deal is one part of Korea's green growth strategy, and has received more attention as it is an alternative which is able to address both environmental-related issues on the one hand, and low-growth on the other. Green growth includes 'Low Carbon Green Growth'. This strategy prioritizes growth that harmonizes the economy with the natural environment through research into clean energy and green technologies, and by saving and efficiently using energy and resources, thus striving to alleviate climate change hazards and to reduce environmental damage (Yun, 2009). The term 'Green Growth' emerged at The Fifth Ministerial Conference on Environment and Development in Asia and the Pacific organized by the UN Economic and Social Commission for Asia Pacific (UN ESCAP). It was promoted to prevent environmental pollution at different stages of economic development. Therefore, green growth is different from sustainable development in that sustainable development aims to *restore* polluted environmental conditions which are the result of economic growth. Green growth, by way of comparison, also seeks to simultaneously achieve both poverty reduction and environmental sustainability (Yun, 2009).

The significance of green growth is increasing in Korea because it can be a solution to overcome not only environmental-related issues, but also low rates of economic growth. Concerning the environment, according to Lee's (2012) work, the average temperature in Korea has doubled over and above the global average, and this has resulted in the sea level rising by 22 cm over the last 40 years. Moreover, the frequency of extreme climate swings has increased because of global warming. In addition to environmental-related issues, the subprime mortgage crisis that erupted roughly a decade ago led to a global economic slowdown. As a result, demand for a new engine of growth emerged, and this is where the green growth concept played, and on the heels of the Covid-19 pandemic continues to play, an important role. As the definition of green growth demonstrates, because the core purpose concerns creating new growth engines and economic opportunities via green technologies and clean energy (Yun, 2009), green growth has been given increasing consideration globally as a new growth paradigm.

Green growth is reflected in Korean policies for industrial complexes at the national level; an Eco-Industrial Park (EIP) is one of example. Lowe (2001) suggests that an EIP is an aggregation of manufacturing firms which seek a balance between environmental, economic, and social benefits through exchange of energy, water, materials, and by-products. The Ministry of Commerce, Industry, and Energy (MOCIE) made an announcement in 2003 about a 15-year master plan for EIP development in Korea (Park et al., 2016), and the Korea Industrial Complex Corporation (KICOX) took over the authority of the plan to facilitate actor participation and the formation of resource-sharing relationships (Park et al., 2016). This plan consists of three phases: 1) the establishment of the foundation of the plan through experimentation with five pilot industrial complexes (November 2005 – May 2010); 2) the period of network expansion, the expansion of physical resources exchange through knowledge exchange, and of expansion of connections to the other pilot sites a hub-and-spoke type of networks (June 2010 – December 2014); and 3) completion of a national EIP network and the development of a Korean EIP model (January 2015 – December 2019) (Park et al., 2016).

In addition to policy implemented at the national level, the regional government also made a contribution to the green industrial complexes in the Ulsan Metropolitan City. A Regional Eco-Industrial Development (EID) team was put in charge of planning, decision making, and policy implementation on behalf of the Korea National Cleaner Production Center (KNCPC) (Park, et al., 2008), and the regional government, Ulsan Metropolitan City, coordinated and organized housing, municipal services, and infrastructure development for the EIP plan (Park et al., 2008).

1.2. Research Purpose

Given the above, the purpose of this thesis is to explore one facet of green growth in Korea, namely the evolution in (and of) an industrial complex (see Essletzbichler & Rigby, 2007), especially focusing on firms in the petrochemical industry. More specifically, this research analyzes evolutionary processes at the Ulsan-Mipo National Industrial Complex (UMNIC), an industrial complex once represented by brown growth, and how green growth policy has potentially impacted petrochemical firms located in the UMNIC and economic-geographical evolutionary processes associated with the complex itself. Rather than simply casting light on Korea's EIP in general, this research focuses instead on this one specific industrial complex in order to gain insight into green evolutionary processes impacting firms *and* resources in an industrial complex from a multi-actor, multi-spatial perspective.

In terms of theory, this research will deploy an Evolutionary Economic Geography (EEG hereafter) framework inclusive of industrial symbiosis considerations. The use of EEG in economic geographical analysis has steadily grown in popularity (Boschma & Frenken, 2006). However, in terms of research into green growth-oriented research utilizing EEG precepts, there is a decided dearth of literature. Park (2008) and later Patchell and Hayter (2013) suggest the use of EEG in their efforts connected to environmentally-based study, and are therefore noteworthy exceptions, but the works are largely theoretical. In the case of Park's (2019) work, although it uses EEG and conjoined concepts such as path creation and new industrial emergence, it focuses more on theoretical aspects, and any application to the Korean case in particular is tenuous. Gress (2019) gives the most recent EEG insight about a Korea-based case, the International Science and Business Belt project, but given the emphasis in that work on the *genesis* of the endeavor, firms are necessarily given less attention compared to the role of policy and institutions. The work of Fornahl et al. (2012) sheds light on processes of new path development in a shipbuilding industry and an offshore wind energy industry in Northern Germany, and pays more attention to the local conditions such as the existing available infrastructure, human capitals, and policy support as determinants for new path development. This work, however, insufficiently deals with the importance of knowledge flows, innovation, and novelty, which are core to the EEG approach in economic geography. Accordingly, in this respect, the present research gives more consideration to those factors.

In this sense, the first contribution of the present research is that it sheds more light on petrochemical *firm evolution* in the UMNIC and the evolution of the UMNIC itself via an examination of possible path dependence (Martin & Sunley, 2006), path diversification (Grillitch & Asheim, 2018), and path creation/development (Trippl et al., 2019) connected to green growth, in addition to institutional impacts (Boschma & Frenken, 2009) to include impacts from policy (Boschma, 2009; Glückler, 2007). Industrial symbiosis, defined as, "…engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products" (Chertow, 2007, p. 12), helps to better operationalize specificities associated with firm, complex, and extra-regional-level green growth-oriented relationships and evolution given the fact that EIP have a resource sharing imperative (see Park et al., 2016).

Second, this research seeks to provide a fresh, *economic* geographical look into green growth in Korea. During the former Lee administration, green growth took on the form of Korea's Green New Deal (see Moon, 2010). Because the policies were highly politicized, studies about green growth tended to concentrate on the political dimension (see Lee, 2009; Yun, 2009; Yun, 2012).

1.3 Thesis Outline

The remainder of this thesis is organized as follows. The following chapter, Chapter 2, consists of the theoretical framework highlighting concepts core to this study. The framework mainly encompasses precepts core to EEG theorizing such as path-dependence, path diversification, and path creation, in addition to the treatment of institutions and policy in EEG. This chapter also includes a discussion of industrial symbiosis, to include some standing examples. The next chapter, Chapter 3, offers a general overview and background of the research topic, namely the petrochemical industry, the petrochemical industry in Korea, and how this industry is embedded in the UMNIC. Next, chapter 4 presents the case study of the UMNIC, including sections outlining the research questions, data and methodology, results, and subsequent analyses. Finally, this thesis concludes with a brief summary, limitations to the research, and implications for future research.

2. Theoretical Background

2.1 Evolutionary Economic Geography

Boschma and Martin (2007, p. 540) denote that EEG, "…is quintessentially concerned with the spatialities of economic novelty (innovations, new firms, new industries), with how the spatial structures of the economy emerge from the micro-behaviours of economic agents (individuals, firms, institutions)," including place-based characteristics and the importance of path creation and path dependence. EEG explores unevenly distributed economic activities such as production, circulation, exchange, distribution, and consumption *across space*, and how they evolve over time (Boschma & Martin, 2010). Furthermore, deploying concepts from ecological and biological evolutionary theory, namely routine, path dependence, and selection, EEG investigates changes in economic landscapes, industrial dynamics, and how these impact regional economies and development trajectories (Hassink, Klaerding, & Marques, 2014).

In the 1970s, modern evolutionary economics criticized the core assumptions of neoclassical economics, namely rationality and perfect information (Nelson & Winter, 1974) because the neoclassical approach was not sufficient enough to explain economic growth (Nelson & Winter 1982), technological change (Arthur, 1989), and industrial evolution (Klepper, 2001) in detail. Those topics were also important in the field of economic geography, so economic geographers started trying to integrate other fields of studies such as heterodox economics (to include evolutionary economics) and other non-economic social sciences (Boschma & Martin, 2010; Hassink, Klaerding, & Marques, 2014). As a result of these efforts, EEG developed as one theoretical framework in economic geography focusing on the development of, and innovation in, regional innovation systems

(Uyarra, 2010) and clusters (Staber, 2010).

The organizational routine is a key concept in EEG, primarily because it is a routine that has a strong influence on firm behavior (Boschma & Frenken, 2006a). It is therefore possible to understand industrial competitive advantages at the micro-level by examining other spatial layers and firm interactions (Boschma & Martin, 2007). Thus, the evolution of regions or clusters are dependent on various forms of organizational routines (Boschma & Frenken, 2006a). Moreover, routines, embedded in firms, can make a contribution on the evolution of clusters either via spillover effects or the creation of spinoffs (Boschma & Frenken, 2006b).

2.2 Theoretical Foundation

There are three theoretical foundations which underpin EEG (Boschma & Martin, 2010). First, as the term (biological) evolution demonstrates, generalized Darwinism is the core theoretical cornerstone of the evolutionary approach in economic geography. Some scholars such as Witt (2003) and Metcalfe (2005) who advocate this view explain economic landscapes by introducing evolutionary concepts into the social sciences which used to be deployed only in the natural sciences. For example, they adopt concepts of evolutionary theory such as variety, selection, novelty, and retention, and utilize them to understand human societies. To be more specific, actors in societies have their own organizational routines, and they experience natural selection process in a social context. In other words, even though there are many different types of organizational routines existing, only some of the routines with strong competitiveness are able to survive, and these successful routines are transferred to the future generation. These competitive routines become dominant in an industry and are diffused within a region (Boschma & Martin, 2010)

If plugging this into an examination of an economic space, the results are as follows: Each firm has their own organizational routines at the micro-level, and only some of the routines with competitiveness, for example cost or process technology competitiveness, are capable of surviving, so they function as industrial paradigms leading the industries (Boschma & Frenken, 2006b). This paradigm enjoys its position in power for a while, but if better routines come up, they will fall behind and finally lose their industrial dominance. In addition to the industrial life cycle, each region has various variety, selection, and retention mechanisms, and this heterogeneousness contributes to the development of different economic landscapes (Boschma & Martin, 2010).

Second, another theoretical foundation of EEG is path dependence (Boschma & Martin, 2010). Under the conceptualization of path dependence, an outcome depends on pre-existing firm-level process's or a system's own history; accidental historical events can therefore have long-lasting impacts on outcomes (Martin & Sunley, 2006). If applying this to economic geography, path dependence refers to economic landscapes as evolutionary systems that are under the impacts of their past development paths or trajectories, so they tend to have multiple equilibria states rather than a single equilibrium state (Martin & Sunley, 2006). In other words, the processes of economic space development tend to follow the existing developmental trajectories, and they do not largely deviate from the trajectory. However, according to the work of Martin and Sunley (2006), this aspect of EEG theory has two weaknesses. First, the conceptualization of scale is vague. It is not very clear when defining the major economic agents who follow a regional economic development path whether they are firms, industries, or regions themselves. Second, there are doubts over whether multiple path-coexistence are feasible or not, and that path development processes are ambiguous. The present research seeks to minimize these weaknesses by concentrating on firm-level analyses, and firm-firm interactions within and across space, in addition to 'scaling up' so as to inquire after policy impacts (good or bad).

Finally, the last theoretical pillar supporting EEG is complexity theory. Foster (2005) argues that evolutionary biology is sufficient enough to explain fundamental *physical* levels of enquiry, but because of its limited application, it is challenging to fully examine *socio-economic contexts*, so there is a need for a new framework, complexity theory, which is able to provide a full explanation in the social sciences. Even though the first discussion about complexity, or complex systems, go back to the 1940s, it was not until the 1970s-1980s that the utilities of the concept such as nonlinear functions and far-from-equilibrium were recognized, so the theory was reorganized as a science of complexity, or simply complexity (Nicolis & Prigogine, 1989). Recently, the utility of complexity theory has won recognition, and the use of complexity theory has widely spread not only into the natural sciences, but also into the social sciences (Reed & Harvey, 1992). For the purposes of the present research, complexity theory concerns open systems, their entities, and their interaction with the environment (Boschma & Martin, 2010). Each system entity locates in a different scale or hierarchy, but they form networks transcending these spatial differences. Therefore, complexity theory is a useful approach to study about evolution and changes of the spatial structure of an economy from a multi-spatial perspective, and different place-based abilities in terms of adaptation and the resilience of some regional economies (Martin & Sunley, 2006).

2.3 Recent Research Strands

Based on contemporary theoretical foundations, Essletzbichler and Rigby (2007) classify EEG research strands into three different types. The first strand explores changes in regional economies and regional evolution led by innovation and technological changes. Therefore, as they relate, the primary research focus is on national innovation systems and regional innovation systems embedded within them (Lundvall, 1992; Gregerson & Johnson, 1997; Brazyk et al. 1998), learning region (Maskell & Malmberg, 1999), and competence regions (Lawson, 1999), which are the birthplace of innovation and technological change. Regions, in short, have been identified as places of the production of novelty (Essletzbichler & Rigby, 2007) and in order to promote innovative activities, there is a need to construct a functional institutional infrastructure of knowledge exchange (Teece, 1986), and relationships between the regional actors (Cooke & Morgan, 1998). At the firm level, innovation activities by firms are conditioned by bounded rationality (Simon, 1957) and firm routines (Essletzbichler & Rigby, 2007). This process is described as local search and learning leading to geographically localized path-dependent evolution of technology routines (Essletzbichler & Rigby, 2007) and all of the activities bring about the co-evolution of institution, firms and technologies (Nelson, 2001). In the present research, firm-firm interaction is examined vis-à-vis the symbiotic use of resources on the one hand, and via analysis of cooperation and their innovation-oriented networks. Institutions are examined via firm perceptions of impacts from policies, again both good or bad.

The second EEG research strand concerns firms, industries, clusters, and regional life-cycles (Essletzbichler & Rigby, 2007). These authors cite works by Griliches (1957), Utterback and Abernathy (1975), Abernathy and Utterback (1978), Klepper and Graddy (1990), Klepper (1996) and Utterback and Suarez

(1993) to describe how product and industry life-cycles influence the spatial evolution of a firm *and* an industry. The key observation of these works is that processes of evolutionary change have a different degree of intensity over an industry life-cycle (see Essletzbichler & Rigby, 2007). At the beginning stage, innovation comes into being at the product-level, and as an industry progresses over time and eventually enters the mature stage, innovation moves from the product-level to the process-level (Sahal, 1981; Dosi, 1982). Meanwhile over the course of this process, firms enter and exit the market experiencing competitive selection pressure leading to the narrowing of heterogeneity and an increasing rate of market concentration (Essletzbichler & Rigby, 2007). There are three approaches to analyze the spatial evolution of an industry (Essletzbichler & Rigby 2007). First, Arthur (1994) highlights path dependence and tries to explain spatial evolution using the locational strategies of entrants. Second, Klepper and Simmon's (2000) work accounts for industrial evolution caused by spin-off dynamics. Third, Boschma and Van der Knnap (1997) understand regional evolution and the lock-in effects using a concept of windows of locational opportunity (WLO). In this approach, agglomeration functions as a catalyst which facilitates the transforming of a region with poor industrial infrastructure to a newly emerging industrial region. This process is called industrial territorialization by Storper and Walker (1989). The present research considers evolutionary growth spurred on by spinoffs (see also Gress, 2019, for a discussion of spinoff potential in Korea).

The third strand of EEG research is the role of institutions and socio-economic culture (Essletzbichler & Rigby 2007). Under the realm of EEG in the past, the roles of institutions received less attention (Gress, 2019; Hassink, Klaerding, & Marques, 2014). In the past, a lot of research focused only on how *formal* institutions (e.g. codified rules) affected regional economic performance (Lundvall, 1992). However, on the heels of an institutional turn that occurred during the early to mid-1990s, it has been proved that the influences of institutions including *informal* institutions (e.g. common culture, trust) on economic development cannot be ignored (Amin & Thrift, 1994; Rodríguez-Pose, 2013). Institutions are geographically embedded in a certain region and the institutions bring about differences in regional economies via region-specific pressure (Essletzibichler & Rigby, 2007). The processes associated with the genesis and development of institutions vary depending on regions (Ibid, 2007). Each region has its own institutions, and these institutions impact the environment, especially the economic space, actors within them, and consequently shape the economic landscape. As Polanyi argued (see Gertler, 2010), economic practices are shaped by socially formed structures called institutions and institutions exert great power on the characteristics of regional economies and the regional evolutionary trajectories. In the present research, institutions are approached via the perceived importance of rules and regulations.

2.4 Institutions and EEG

As Boschma and Frenken (2006a) concluded, EEG is able to offer new explanations for the main questions posed in economic geography - namely those connected to locational patterns of firms, the spatial evolution of sectors and networks, the co-evolution of firms, technologies and territorial institutions, and convergence and divergence in spatial system, and this is where the treatment of institutions is vital in the field of EEG. Some skepticism about the power of institutions in the field of EEG was voiced by Bathelt and Glückler (2003) and

MacKinnon et al. (2009), namely that the place-based relationship between the impacts of institutions and firm networking was not clearly recognized, and that the effect of institutions on routines would be small as firms develop in a path dependent and particular manner. Boschma and Frenken (2009), however, later discovered that institutional change enabled the growth of new industries and the revitalization of old industries. According to them, institutions develop purposefully to usher in more growth in a new industry. Institutions, however, are sticky (Martin & Sunley, 2006). In other words, institutions are place-based and do not immediately change. It takes some time to adapt to the new industrial environment created from industrial evolution. More akin to the work of Boschma and Frenken (2009), Freeman and Perez (1988) argued that institutions will transform to make new industries fully develop. As a result, industrial-specific institutions will *co*-evolve with the existing institutional assets.

Institutions have a strong impact on economic activities, namely on the evolutionary trajectories of regional economies, so they are emphasized in the field of economic geography when it comes to EEG based inquiry (Gertler, 2010). In case of Institutional Economic Geography (IEG), each region develops their own regional or territorial-specific institutions and these differences construct the heterogeneity in a regional economy. In other words, different institutions such as governance, policies, and agency shape different place–specific developmental trajectories, and these build what we understand to be heterogeneous economic landscapes (Gertler, 2010). Bochma and Frenken (2009, pp. 154-155) suggest, for example, that "…institutional change is required to enable the emergence of new industries and the revival of mature industries." Indeed, they further state, "What is crucial, though, is that such institutions are created deliberately to support and sustain the further growth of the new industry." As in other works, though, the approach is decidedly firm oriented, their key delineation between EEG and Institutional Economic Geography (IEG) being that IEG examines growth via a territorial institutional lens, whereas EEG concentrates on firm level routines. In the end, they are reticent when it comes to the ability of institutions, or policy, to determine the location of a fledgling industry and leave the question open as a challenge to future researchers. To others, institutional change, however, is seen as important to development efforts (Hassink, 2005). The present research on a Korean case, much as suggested by Gress (2019), may help to answer this question.

However, Boschma and Freken (2009), in contrast to IEG, argue that territories are characterized by a variety of firm routines and firms are able to apply their own routines in different territorial domain contexts. Putting it differently, it is not merely that an economic landscape is shaped by institutions, but that it is firm's own behavior or routines that help to form heterogeneity among economic landscape. Firms develop their own ways of economic activities such as production, consumption, and distribution, and these activities bring about heterogeneity among economic landscape according to regions (Boschma & Martin, 2010).

EEG is well aware of the existence and importance of territorial institutions, but such structure is not that tight, so it lacks of the ability to determine the behavior of firms and industrial dynamics (Boschma & Frenken, 2009). For example, local firms in clusters demonstrate different degrees of network connectivity even though they are under the same scope of territorial institutions (Boschma & Ter Wal 2007; Giuliani 2007; Morrison, 2008). Moreover, *territorial* institutions may be losing importance as a strong factor shaping an economic system. Evolutionary scholars are now paying more attention to *sectoral* institutions for economic activities, especially firms' behavior, rather than territorial institutions (Boschma & Frenken, 2009). This means that in certain production space consisting of a single supply chain, specific sectoral institutions develop at each phase of the production process. There is a statistical evidence supporting this phenomenon - that sectoral-institutional analysis, rather than a regional or territorial institutional approach, would be a dominant factor leading to the diverse patterns in innovation and of firms (see Breschi, 2000).

2.5 Policy and EEG

Policy can transform a region and the economic landscape through evolutionary processes such as spinoff dynamics, labor mobility, and network formation (Boschma, 2009). For example, the state sought to design the offshore wind energy sector in North East England and in Scotland to rebalance the localized economies (Dawley et al, 2015). In other work, transition processes with respect to path creation were mediated by local and regional policy makers (Glückler, 2007). Furthermore, EEG-based work on Korean policy showed that the state is involved in the process of organizational knowledge creation, while at the same time organizing itself as more of a constituent actor rather than a top-down, dirigiste controller, largely because local rather national-level processes tend to work better during the creation of new innovative architectures (see Gress, 2019). This process plays an important role in the evolution of cluster via spillover effects or the emergence of spinoffs (Boschma & Frenken, 2006a), a contingency that, again, is studied in the present research.

Luck or serendipity may function as a triggering factor for economic evolution. As Boschma (2004) suggests, new development paths may not be predicted, but this is not to say that the power of policy on path development is negligible, but that new paths can pop-up based on chance events rather than on those pre-selected by policy makers. This is a question central to EEG-based research (see Gress, 2019).

In spite of contingency, Martin and Sunley (2006), for example, argue that the impact of agency is a stronger factor than luck or serendipity. They also note that the role and strategic decisions of policy-makers have to be given more attention so as to appropriately understand regional path development, especially path creation. In addition, the works of Rodriguez-Pose and di Cataldo (2015), and of Koschatzky and Stahlecker (2006) also emphasize the importance of policy by highlighting that successful regional development is attributed *a priori* to public governance.

In the history of economic development in Korea, the role of policy and the state has evolved. In the past, based on the developmental state model, the characteristics of development took the form of a top-down, or dirigiste, approach (Hassink, 2004). In this approach, the state was able to coordinate most economic activities because it was the principal agent boosting infrastructure, institutions, and regulations (Brenner, 2004). However, entering into the modern era, the power of the state on economic development has transformed. Oil shocks led to governmental failure and this spurred the rise of neo-liberalism which addressed the power of markets; this, in turn, brought about the idea that a state was not the only strong influencer on economic activities (Cooke & Morgan, 1999). This also backs up Storper's (2005, 41) premise that the 'political isolation' perspective does not sufficiently capture the nature of coalitions and institutions that helped countries like Korea and Japan to develop.

Furthermore, as the present knowledge-based economy began to grow, knowledge took center stage in terms of creating value, and this became directly related to economic development and growth. So to speak, other factors got more attention than the state. For example, firms create, transfer and exchange knowledge through social networks and interaction (Boari & Lipparini, 1999). This view corresponds to the EEG perspective, particularly the role that routines, embedded within firms, play in the evolution of clusters, whether via spillover effects or the creation of spinoffs (Boschma & Frenken, 2006a). In the knowledge flow process, however, inefficiency takes place because of misallocation of resources (Coenen et al., 2017) and this is where a government may intervene. A government coordinates economic activities to adjust misallocation and encourages spin-off activities to make a region move into a new path (Boschma & Frenken, 2006a).

Policy may be a great trigger for geographical evolution, but it is not the only determinant. If switching the scale, there are other strong factors such as local governments and firms. At the firm level, innovation is an important element, and this innovation is highly supported by local decision makers (Boschma & Frenken, 2006a). In the knowledge-based economy, it is essential to bring new innovations to markets, and this is where regional-level innovative structures play an important role (Maskell & Malmberg, 1999). Furthermore, when it comes to path development resulted from spillover effects, organizational routines embedded within firms, play a role in the evolution of clusters (Boschma & Frenken, 2006a).

Boschma (2005) classifies regional policy into two types, evolutionary and revolutionary, and Boschma and Frenken (2006a) analyze the policy types as follows.

Table 1 - Evolutionary versus Revolutionary Policy Types in EEG

Evolutionary type of policy	Revolutionary type of policy
Location-specific policy	Generic policy
Fine-tuning	Restructuring of institutional framework
Strengthening existing connectivity	Stimulating new connections
Benefiting from specialization	Stimulating diversity
Few degrees of freedom	More degrees of freedom
Less uncertainty	More uncertainty

Source: Adapted from Boschma (2005)

First, evolutionary policy is based on local-specific contexts and aims to intensify the connectivity among the elements and regional systems by fine-tuning policy. Therefore, although policy-makers have a low level of degrees of freedom, if their actions are well localized, firms will be more likely to succeed by reproducing and by reinforcing existing structures. In this case, local endowments are important in determining available options and outcomes of regional policy.

In contrast to evolutionary policy, revolutionary policy restructures the social and institutional systems by building new regional systems, increasing diversity and a high degree of openness regarding the inflow of labor, capital, and knowledge (Boschma & Frenken, 2006a). In this case, policy-makers have a higher level of freedom, but uncertainty may hinder the success. Unlike evolutionary policy, path dependence exerts less influence, so local-specific contexts are also less powerful in this regime, and this leads to new developmental trajectories of industries. The present research is designed to utilize firm input regarding their connections and innovative behavior to ascertain the mode of green growth policy being deployed in the complex.

2.6 Path Dependence

In Martin's (2010, p. 5) *Roepke Lecture in Economic Geography,* institutions are introduced as a means by which to reinvigorate notions of path dependency and lock-in, the author adding, "Presumably, a convincing model of local industrial evolution would attempt to provide some explanation of why and how new local industrial and technological paths emerge where they do." From the outset, it is important to have a solid understanding about the concept of path-dependence, which is the foundation of path development. Path-dependence refers to an outcome if under the influences of the previous trajectory or processes of system's own history (Martin & Sunley, 2006). Smith, Rossiter, and McDonald-Junor (2017, p. 493) define path dependence as, "a region's future paths of development are constrained by the products of social and economic history: accumulations of capital (human and physical), concentrations of expertise, productive infrastructure and institutional architecture etc." When a certain path becomes dominant in the region, a lock-in effect takes place, and the lock-in effect disturbs the emergence of an alternative path (Boschma & Lambooy, 1999; Boschma, 2004; Martin & Sunley, 2006; Boschma, 2015). Therefore, even though an existing path may be suboptimal or inefficient, the system is maintained because the system relies on the *existing* path. If applying this mechanism to the study of an industry, the succeeding industry demonstrates the tendency to follow the existing industry. For example, if there is a region with lumber resources, lumber-related industries such the furniture industry would develop first. It is reasonable to infer there would then be succeeding industries emerging which are related to those existing industries because the existing industries already have the requisite industrial infrastructure, and the successive industries have a no reason not to utilize them. Through this process, the region firmly intensifies its industrial infrastructures and industries would tend to depend on the them.

Arthur (1989) argues that increasing returns exert power to generate path dependence in the economy. This approach also can be applicable to the case of Korea's petrochemical industry because the characteristics of the industry correspond to such types of increasing returns. First, increasing returns involve large fixed, initial, set-up costs (Arthur, 1989). The petrochemical industry is also highly capital-intensive, so it requires a huge investment at the early stage (Nam, 2015), but this industry has economies of scale (Hwang, n.d.), so as the output increases, the unit cost decreases. The Naptha Cracking Center (NCC) is a core facility of the industry and there is a tendency that other relevant firms locate near the center forming a systematic industrial complex (Hwang, n.d.). This is where learning processes happen. Different types of learning processes, for example learning by doing, learning by interacting, and learning by using, function as positive feedbacks (Arthur, 1989) intensifying the dependence on the existing path.

Martin and Sunley (2006) suggest that regional technological lock-in is related to path dependence. In the case of the petrochemical industry, which generates about 50% of sales in UMNIC (KICOX, 2019), it is a highly capital- and technology-intensive industry as well as being specialized in specific sectors. As a result, the current technology level and markets have entered the mature stage (Nam, 2015) and the industry has faced technological lock-in because of the inertia of high sunk costs of its existing technology, infrastructure, and capital (Martin & Sunley, 2006) and high costs for investment in R&D or innovation.

In addition to technological lock-in, economies of agglomeration also can be connected to path dependence (Martin & Sunley, 2006). As stated above, the petrochemical industry operates in industrial complexes, so there are many other related actors involved giving rise to economies of agglomeration and agglomeration externalities. The externalities include labor, markets, networks with other actors within the complex, and information and knowledge exchange. These agglomeration externalities construct a robust industrial system intensifying the dependency on it. The present research examines these externalities vis-à-vis firm-level activity, industrial symbiosis, and green growth policy.

2.7 Path Creation

Even though a path may be under the influence of the past trajectory, if firms can nonetheless deviate; this is called path creation. To be more specific, path creation, in case of an industrial context, refers to the rise of entirely new industries in a region, which often stem from commercialization of research results (Tripple, Grillitsch, & Isaksen, 2018). From the perspective of green growth, green path creation denotes the emergence of new *green-related* industries (path creation) or the introduction of green-related industries that are new to the region (path importation) (Trippl et al., 2019), or green-related production processes and products, and of new green technology based on green innovative activities. The present research examines these potentialities.

Path creation can be triggered by an influx of individual and organizational actors from outside because those are carriers of new knowledge and external sources for innovation (Isaksen & Trippl, 2017; Trippl, Grillitsch, & Isaksen, 2018). In our knowledge-based economy, knowledge has become one of the most important factors for innovation and industrial growth (Crevoisier & Jeannerat, 2009; Park, 2008), and knowledge-related processes may be supported by external linkages. This is supported by the work of Binz et al. (2016) who emphasizes the importance of external linkages for new path creation. The existing knowledge in a region may have lost its motive to produce new knowledge or combine with other knowledge. In this sense, new sources from outside are able to infuse new life into the region. Generally speaking, new information and knowledge flow into a certain region can function as ignition for innovation leading to path creation. The new information and knowledge are combined and interact with existing information, knowledge, and technologies. Novelty is produced as the outcome of those processes and this novelty triggers innovation leading to the emergence of new industries (Boschma & Frenken, 2011). The present research therefore examines not only firm interactions, but also does so at multiple spatial scales simultaneously (e.g. within the complex/region, with another region, and internationally).

However, information and knowledge are not the only factors stimulating path creation. Institutions, as previously discussed, both formal and informal, are also strong factors which can create a path. For example, policy support is also able to make a positive impact on a development of a new industrial path. According to Smith, Rossiter, and McDonald-Junior's work (2017), for example, Nottingham, England was able to transform itself into a biotechnology-specialized city due to the contribution of both scientific and administrative organizations and the increase in power of autonomy of the regional government during the planning. In addition, in the case of Fuxin, China, the development of the wind power industry was attributed to state-led path creation through not only financial support, but also institutional supports such as domestic trade protection, price regulation, and tax cuts from the state (Hu, 2014). Besides these factors, the mobilization and anchor of firm and non-firm actors are significant for the formation of an industry (Binz et al., 2016). The present research examines firm use of government and private R&D,

industry associations, business assistance programs, and consortia in addition to firm-level perceptions of policy support**.** Perhaps even more important, barriers to firm-level business activity are examined, including barriers resulting from policy.

A new path can be generated at various scales. To begin with, a new path can be generated from within a firm. It is possible for firms to have industrial innovation through their own R&D activities, and this innovation comes with structural changes within the firms namely levels of products or production processes (Cohen & Klepper, 1996). This mechanism leads to organizational restructuring, or evolution *in* the industry, like developing new products, processes, or launching new business. Path creation does not stop at evolution in the industry. The scale transcends the border of evolution *in* the industry to evolution *of* the industry. Unlike new path development for an individual firm, a new *industrial* path reflects characteristics of the industry which are a collection of firms in the industrial region. In a similar vein, Essletzbichlar and Rigby (2007) discuss evolution *of* a region versus evolution *in* the region, which is a scaled-up version of the evolution. The collection of the evolution of firms constitutes the evolution of the industry, and the collection of the industrial revolution again constitutes the evolution of the region.

In the case of path creation, it would be useful to demonstrate industrial and regional evolution because of the emergence of unprecedented industries which are completely distinguished from the existing industries. One of the distinct characteristics of evolution in social sciences is irreversibility (Boschma & Martin, 2007; Ma & Hassink, 2013). Once a certain industry takes root, increasing returns such as economies of scale or dynamic learning effects take place for a while and the return comes with a positive lock-in effect, so the region relies on the industrial path (Martin & Sunley, 2006). This process is self-reinforcing, and because there is no motivation to deviate from the path, the dependency gets intensified as long as the positive lock-in effect is dominant. Conversely, when a technological system becomes mature and loses its industrial competitiveness, a negative lock-in effect develops and there is a motivation to create a new path to break the momentum of the downturn (Martin & Sunley, 2006). Therefore, through comparison of the old and new state of economic landscape, it is possible to have a solid understanding about the evolution of an industry and a region.

Path creation can be applicable as a way of growth. In the past, growth characterized as brown growth centered on economic development dependent on fossil fuels. It did not consider the negative impacts that economic activities such as production and consumption have on the environment. Based on new technologies and better awareness about the environment, however, there is a need for a new way of growth, green growth, and this may bring about a new path creation. Firms in the present study are therefore directly asked about their motivations for their green growth initiatives as well as their outcomes.

Examples of new paths emerging from green growth can be found in the literature. First of all, Steen and Karlsen (2014) illustrate an excellent example of a new path into green growth. According to their work, Verdal, Norway used to be well known for brown growth because it was a region which developed from the oil and gas industries. However, an economic crisis hit the region, so the municipal government had to implement a restructuring program in order to revitalize the economy. The program upgraded the local knowledge base and diversified firms. As a result, the region which used to be represented by oil and gas industries transformed into one based around wind power industries, an excellent example of green growth-oriented path creation. In addition, Martin and Martin (2017) identify the region of Scania, Sweden, which has created a new industrial path into the biogas industry. With great industrial endowments such as the existing food industry and agriculture, the policy of the Swedish Environmental Protection Agency played a role in developing the new, green industrial path.

2.8 Path Diversification

Path diversification refers to the emergence of newly diversified industries which can be either related or unrelated, or to those resulted from a new combination of existing regional resources (Trippl, Grillitsch & Isaksen, 2018). From the perspective of green growth, path diversification stands for the development of a green industry from the combination of knowledge and resources of existing green industries, or the transformation of a brown industry into a green industry which is either related or unrelated to the existing economic structures (Trippl et al., 2019). The present research accordingly asks firms whether or not they have generated new technologies or spinoff firms resulting from green growth (complex) policies.

The advent of path diversification is attributed to networks (Grillitsch & Asheim, 2018). As the definition suggests, path diversification is based on the combination of existing knowledge assets. In this sense, it is networks which function as a lubricant making this process smooth and connecting the actors (Grillitsch, 2016). Robust networks offer more opportunities to combine and exchange knowledge and resources (Grillitsch & Asheim, 2018), and based on these interactions, existing paths may diversify into various paths via the reproduction of knowledge and resources. Furthermore, networks between sectors also contribute to innovation. For example, there is increasing evidence that the interaction among industry, both related and unrelated (Asheim et al., 2011), research, public services, and civil society (Carayannis & Rakhmatullin, 2014) is able to provide opportunity for knowledge and resources combinations (Grillitsch, 2016). The present research takes these potentialities into consideration.

Path diversification, which is often represented as industrial diversification under economic geography, can come in on a smaller scale. First of all, Grillitch and Asheim (2018) suggest that industrial diversification is a firm-level process. Thus, in this case, industrial diversification takes the forms of intra-firm-level diversification of products, processes, and technologies. Intra-firm diversification may be carried out via new knowledge and innovation that create better ways (though perhaps not very different from the existing ones) to improve the firm's existing products, processes, and technologies. However, firms' industrial activities are not limited to the intra-firm level. They can also be done at an inter-firm level, thereby increasing the potential breadth of path diversification. New knowledge and innovation offers a new way for industrial activities. From a green industry viewpoint, the concept of asset modification which involves the redeployment and recombination of the existing assets (Trippl et al., 2019) is key to understanding the genesis of pathway diversification. Firms, for example, may have diversified *some* parts of their industrial processes, for example diversification of a material management method like resource-sharing, in conjunction with related firms. This corresponds to the concept of industrial symbiosis which will be discussed soon.

Networks are conducted in two spatial dimension, local or global (Isaksen & Jakobesen, 2017). In the case of local networks, inter-firm networks in this context, path diversification stems from related variety, regarded as a fundamental mechanism in EEG theorizing (Frenken & Boschma, 2007). In same geographical space, related variety means that actors share knowledge and resources, and similar access to the endowments provide similar industrial foundations for the actors or regions; path can be diversified because this relatedness is a strong driver of industrial diversification (Boschma et al., 2017). For example, an industrial foundation such as the installation of an oil platform can be utilized for the installation of offshore wind parks, and through this, the industrial base in the region can transform into one specialized in renewable energy (Grillitsch & Asheim, 2018).

Networks may revive an old industry or a cluster (Isaksen & Jakobsen, 2017). The industry or cluster would get used to their existing industrial environment, so they may have lost their growth engine because of negative lock-in resulted from path dependence (Saviotti & Frenken, 2008). In this case, new knowledge and information are supplied by networks through external linkages, and the new combination of the sources from outside construct a new innovative environment (Bathelt et al., 2004; Nadvi & Halder, 2005). At this point, the balance between local and global sources is important (Fornahl & Tran, 2010; Kramer & Diez, 2011; Montagnana, 2010) because, as Bathelt et al. (2004) insist, when intense local networks coexist with external linkages, they form a synergy effect accelerating collective learning processes for innovation in a cluster. The present research examines these spatial possibilities.

Capability also plays a role in path diversification. Boschma (2017) argues that each region has its own capability such as a combination of the region's infrastructure and built environment, natural resources, and institutional endowment to absorb and utilize external knowledge. Based on capabilities and available knowledge sources, a region specializes in a certain sector and this develops regional diversification. This is not very different from the dimension of industry. There is a difference in industrial capability among each firm, and the difference becomes a criterion for industrial specialization which in turn will be exposed as industrial diversification on an economic landscape. Depending on capabilities, diversification can take the form of the establishment of affiliated firms, spin-off firms, or intra-firm diversification such as diversification of products or production processes. Again, the present research inquires after these possibilities.

The story of path development may also be applicable to Korea. Korea is also keeping pace with the global trend about greening the economy. Since the administration of Myungbak Lee, green growth has been set as a national policy and has actively been implemented following the Presidential Committee on Green Growth (Yun, 2009). Firms are sensitively responding to the policy and the greening of the Ulsan-Mipo National Industrial Complex (UMNIC) is an ideal case to study. As shall be discussed in the ensuing background section, Ulsan-Mipo National Industrial Complex was the very first and the largest national industrial complex in Korea, and it played a role as a growth engine during the period of Korea's rapid economic growth (Nam, 2015). The complex, which has its roots in brown growth, is responding to the recent policy shift, and is making efforts to transform itself via the creation of new paths into green growth.

2.9 The Significance of Paths in an Evolutionary Approach

This evolutionary approach and path is meaningful in two senses. First of all, evolution is not an outcome, but a process (Martin, 2010; Martin & Sunley, 2006). In other words, evolutionary approach is not an analysis about a point or coordinate.

It is more about tracking the journey from one point to the other point along the curve connecting those two points. Therefore, it is necessary to look at the process, so there is a need to pay more attention to the curve, not each point, and this is where path analysis is useful. For example, path creation refers to the emergence of a completely new industry. Path development in turn has the ability to explain how a new industry is introduced and of tracking the industrial dynamics of how the existing or old industries fall behind.

Furthermore, path development can capture the power of external factors, especially policy. When investigating geographical evolutionary processes, the role of external factors of path development tend to be underplayed (Trippl et al., 2017). Gress (2019) gives an explanation of how policy impacts path development using the concepts of adaptation or adaptability which stands for a tendency to recover its functionality and performance back to before the shock as it experiences various structural and organizational changes (Martin & Sunley, 2015). When there is a new industrial policy implemented, it may function as a shock. Therefore, the actors need to react to the shock and new pathways, or new industrial activities, may be expressed in terms of varying degrees of adaption or adaptability (Gress, 2019). Furthermore, the EEG perspective is placing increasing importance on the role of exogenous actors, *resources* (a tie in to the use of industrial symbiosis in the present research), and their influences on path development (Trippl, et al., 2019). This research studies how green growth policy pushed ahead by the state triggers evolutionary processes of and in UMNIC. In this sense, state policy functions as an endogenous factor triggered in part by exogenous factors (e.g. global warming and a global consensus to go green). Therefore, unlike the argument that there is tendency for EEG to overlook the importance of institutions (Mackinnon et al., 2009; Pike et al., 2009), policy influences geographical evolution and this is where path development works.

2.10 Industrial Symbiosis

In the end of 1980s, there was active discussion with respect to the relationship between industry and environment (Chertow, 2007). Frosch and Gallopoulos (1989) introduced a concept of industrial ecosystem which refers to the consumption of energy and with the concept, Kalundborg was selected as a model for industrial symbiosis (Jacobsen, 2006). Both of the discussion have one thing in common, exchanges or recycle of energy and materials.

Chertow (2007, p. 12) defines industrial symbiosis as: "…engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products." It is a different form of exchange from other types of exchange because it has a criterion of 3-2 heuristic criteria: there should be at least three entities for exchange and two different resources for a basic type of industrial symbiosis (Chertow, 2007). By doing like this, it is possible to shed more light on complex relationships among the entities rather than one-way exchange (Chertow, 2007).

Industrial symbiosis is able to provide not only economic benefits, but also environmental benefits. First of all, economic benefits are attributed to synergistic possibility resulted from geographical proximity (Chertow, 2000). Geographical proximity enables the firms to share resources in reducing production and transaction costs and in increasing revenue and this process helps the firms stabilize resource availability through contracts among the firms (Chertow, 2007). In addition to the economic benefits, firms respond to environmental regulations and this becomes a motivation for the firms to figure out a new way to improve efficiency of resource use and to minimize emission and the volume of waste (Chertow, 2007).

2.11 Empirical Examples from across the World

Kalundborg, Denmark is a paradigmatic example of industrial symbiosis (Jacobsen, 2006). Kalundborg experienced a gradual evolutionary process from by-product exchanges into symbiotic inter-relationship between five co-located firms and the local municipality (Ehrenfeld & Gertler, 1997). Five firms, a power plant, an oil refinery, a biotech and pharmaceutical, plasterboard, and soil remediation firms have constructed interdependency in terms of resource exchanges and developed the relationship of industrial symbiosis (Jacobsen, 2006). Currently, there are approximately 20 different by-product exchanges in operation and the industrial symbiosis consists of some of potential projects and projects cancelled because of markets and technological innovations (Jacobsen, 2006).

Industrial symbiosis can be found even in Korea. The idea of industrial symbiosis comes as the form of eco-industrial parks (EIPs). Korea adopted industrial symbiosis strategy in order to transform aged industrial complexes into EIPs which minimize environmental-related issues and maximize resource use efficiency (Park et al., 2016). The Korean government launched the National Eco-Industrial Park Development Program which consisted of three phases gradually constructing eco-industrial networks over 15 years (Park et al., 2019). Park et al. (2019) analyze the three phases as follows. The first phase (2005-2010) aimed to lay the foundation of the program via experimentation of five pilot industrial parks.

The second phase (2010-2014) tried to expand the networks between the parks beyond individual industrial complexes. The third phase (2014-2019) intended to integrate the industrial complexes and urban areas developing national networks.

There are several studies with respect to industrial symbiosis in Korea. Park et al (2016) provides an overall review of the Korean National Eco-Industrial Park Development Program, especially focusing on the first phase of the program. This study explains how Korea developed its own approach to nationwide eco-industrial development and diagnosed what success and limiting factors to improve the program. Park et al. (2019) analyze the evolutionary process of the program with a concept of industrial symbiosis and this study focuses on the scaling-up of industrial symbiosis at the second phase. In case of the work of Park et al. (2008), it traces how an aged industrial complex located in Ulsan has evolved into an eco-industrial park and that national policies and developmental activities have drived the global trend of innovation of greenizing existing industrial complexes.

This research tries to bridge the gap by taking a micro perspective of analysis. The studies stated above explore each phase of EIP program and analyze industrial symbiosis in a macro perspective. Unlike those studies, rather than examining the program itself and taking a macro perspective, this research focuses on actors, the petrochemical firms, in the industrial complex and tries to shed more light on evolutionary processes of their industrial activities and how those are reflected on the industrial symbiosis there.

Industrial symbiosis is an important concept in this research in two senses as follows. First, industrial symbiosis can demonstrate path evolution. Industrial symbiosis is a scale-up process of industrial activities which promotes intra-firm industrial activities to inter-firm level because it is not that firms' industrial activities is not restricted to their production sites, but they frequently transcend across the sites and reach to even sites in overseas in some cases. Besides, at this point of time that EIP Program has been halted because the program with 3-phase has been completed (Park et al., 2016) and environmental issues are getting serious, it is important to how actors in an industrial region develop the relationship of industrial symbiosis in these days.

2.12 Green Growth

Climate change is facilitating the emergence of green growth imperatives. Industrial activity has translated into economic growth, but this growth has come at a cost. In Korea's case, from the 1960s to the late 1990s GNP rose from 82 USD to 10,543 USD (Moon, 2010); Korea is now a developed economy. However, globally, this growth has been a double-edged sword; economic growth also came with a severe environmental impact. The level of carbon dioxide in the atmosphere in 1750 rarely fluctuated, but rapidly increased after industrial revolution, even reaching 379 ppm in 2005; the greenhouse effect is serious, leading to an increase in the surface temperature by 0.74°C and in the sea level by 3.1mm (Kang, 2009).

The beginning of a discussion vis-à-vis two incompatible values, growth and environment, goes back to the Rio Submit in 1992. The United Nations Conference in Environment and Development (UNCED) adopted Agenda 21, reached an agreement to establish a plan for sustainable development, and suggested that participant nations construct a foundation for sustainable development (Yun, 2009). From that time, sustainable development functioned as a new growth strategy and began to exert influence on both national and international environmental policymaking and planning (Jacobs, 2013).

However, sustainable development is suffering from a loss in momentum for political reasons (Jacobs, 2013). The Stockholm Declaration and Rio submit, did lead to environmental legislation and this contribution did something for conservation or the restoration of natural assets (Pallemaert, 1992). However, the idea that natural assets had a first priority over economic growth may not have been viewed as attractive enough for policy-makers because it might have discouraged voters and businesses from taking a supportive position given that any policies related to sustainable development may have had perceived detrimental impacts to economic growth (Jacobs, 2013).

In this sense, green growth emerged as a viable substitute for sustainable development because green growth seeks both economic growth and environmental protections. It was The Fifth Ministerial Conference on Environment and Development in Asia and Pacific organized by the United Nation Economic and Social Commission for Asia and Pacific (UN ESCAP) in 2005 that the term officially appeared (Yun, 2009). In the conference, there was active discussion about how to harmonize economic growth and the environment for poverty reduction for low-growth nations in Asia and Pacific regions. The term is deployed under the process exploring a way to achieve both economic growth for poverty reduction and environment conservation at the same time (Yun, 2009).

Jacobs (2013) identifies three different economic and political approaches to green growth. The first approach is Green Keynesianism. Green Keynesianism considers that it is possible to secure a growth engine through environment-related expenditures. Fiscal policy and the Korean Green New Deal can be the examples of Green Keynesianism. The second approach is growth theory. This approach regards environment destruction as market failure and during the process of overcoming the failure, growth can be achieved. The last approach is comparative advantage and technological revolution. A government sets a new environmental standard and environmental industries develop, thus creating economic opportunities and leading to economic growth through technological innovation; all of these mechanisms are connected to green growth.

Korea's green growth strategy mainly consists of energy, resource circulation, and finance (Mathews, 2012). Taking into consideration industrial symbiosis, the present research tries to shed more light on resource circulation. Mathews (2012) explains resource circulation in Korea using industrial symbiosis relationships taking place at Ulsan petrochemical industrial complex. To be more specific, the author discusses many material transactions occuring in the production chains between Hankuk Paper and Korea Zinc. Korea zinc supplies steam and carbon dioxide generated during production as by-products, and Hankuk paper utilizes the by-products to produce final products (Mathews, 2012). Through these transactions, by-products and waste do not stop at the final stage of a production chain, but continuously circulate, thus transformation from a linear production chain to a circular ecosystem. Similar to this study, the present research also takes resource circulation into account vis-à-vis industrial symbiosis as one mode of path development.

2.13 Summary and Implication for the Thesis

Chapter 2, theoretical background, consisted of five sub-sections, namely EEG, path development, the significance of path development in this study, industrial symbiosis, and green growth. This section briefly summaries the current chapter and proposes two implications for the present research.

First of all, in the first sub-section, a core theoretical framework of the present research, EEG, was discussed. EEG explores, "how geography matters in determining the nature and trajectory of evolution of the economic system" (Boschma & Martin, 2010, p.6), and is supported by three theoretical foundations - generalized Darwinism, path dependence, and complexity theory (Boschma & Martin, 2010). In addition to the theoretical aspects, the sub-section also recounted the recent research trends such as innovation and technological change, firm, industry, cluster, and regional life cycles, and the role of institutions and socio-economic culture (Essletzbichler & Rigby, 2007). The sub-section then demonstrated how institutions and policy are intertwined in economic activities and evolutionary processes.

After the introduction of EEG, the followed sub-section narrowed down the theoretical foundation and addressed a specific framework, path development, including path-dependence, creation, and diversification. Technological lock-in is a major impetus for path dependence (Martin & Sunley, 2006), innovation from knowledge plays a potential role in a new path development (Isaksen & Trippl, 2017; Trippl, Grillitsch, & Isaksen, 2018), and the combination of knowledge is key for path diversification (Trippl, Grillitsch & Isaksen, 2018). This sub-section also gave an explanation about paths as applied to the case of Korea by citing green growth mainly driven by the Korean government.

Moreover, it was argued that deploying the concept of path development would be great in exploring green evolution for two reasons. First, path development is an effective tool to examine industrial evolution as a process because it tracks the industrial dynamics of how existing paths fall behind and how new paths emerges. Second, it is possible to capture the impacts of external factors. The role of external factors tends to be given less attention, but EEG can place more importance on the role of exogenous factors (Trippl et al., 2017).

Fourth, in the fourth sub-section, industrial symbiosis was mainly discussed. Industrial symbiosis stands for, "…physical exchange of materials, energy, water, and by-products among diversified clusters of firms" (Chertow. 2007). Building from the definition, this sub-section also described how the concept of industrial symbiosis emerged, and the motivation for industrial symbiosis (e.g., economic and environmental benefits). A great example of industrial symbiosis in real life, Kalundborg, Denmark, was also suggested. In addition to the case of a foreign country, the sub-section also presented how industrial symbiosis plays a role in contemporary Korea by discussing a case of an Eco-Industrial Park (EIP) and the connection between industrial symbiosis and path development from a geographical lens.

Finally, following the discussion of industrial symbiosis, green growth was addressed. There has been a continuous discussion with respect to the relationship between economic growth and its impact on the environment. The discussion departed from sustainable development, largely because of its imperfection, and an alternative, green growth emerged. This sub-section discussed three different political and economic theoretical conceptualizations - green Keynesianism, growth theory, and comparative advantage and technological revolution. Green growth is also applicable to the case of Korea. For example, Korean green growth includes EIPs and a focus on resource circulation, one pillar of Korea's green growth strategy (Mathews, 2012).

Under the umbrella of EEG theorizing, there is a perceived limitation in that it is not clear who are the main economic agents who participate in regional economic path development and precisely how (see Martin & Sunley, 2006). In this sense, the present research suggests that the petrochemical firms in the UMNIC are leading the processes of path development, though institutional considerations and industrial symbiosis are also foci of the analyses.

In addition, given that there are few existing studies such as Gress (2019) and Park (2008) which deploy EEG in order to study a case in Korea, the present research tries to enrich academic discussion about contemporary green growth tradjectories in Korea from an EEG perspective.

3. Research Background

3.1 The Petrochemical Industry

The petrochemical industry is defined as an industry producing synthetic-fibers, -rubber, and other basic chemical materials with a raw material such as petroleum and natural gas (Korea Petrochemical Industry Association, n.d.). Nam (2015) identifies the general characteristics of this industry: 1) it is a capital-intensive industry requiring massive investment in facilities, 2) it is under the impact of business cycle repeating boom and recession depending on the fluctuation of the world economy and oil price, 3) it is an industry related to other industries, and 4) price competitiveness is the most important in a global market as the technology and market has entered into a mature state. Furthermore, other related industries tend to locate near the petrochemical industry aiming to have agglomeration benefits, and this leads to the formation of an integrated industrial complex. For example, there are three representative industrial complexes in Ulsan, Yeosu, and Daesan, Korea and the development of those complexes is attributed to specialization in the petrochemical industry.

The Korea Institute for Industrial Economics and Trade (KIET) (2015) accounts for about the history of the petrochemical industry as follows. To begin with, oil refinement technology developed because as gasoline was used as a fuel for means of transportation, the demand also increased. This became the background for the development of ethylene technology which is a representative product of the petrochemical industry. Meanwhile, Standard Oil launched and operated Naptha Cracking Centers, and these became the beginning of the petrochemical industry. In the 1930s, chemical engineering was applied to the petroleum industry and this led to the development of synthetic detergents and synthetic resins. After World War II, the petrochemical industry developed into its current form having experienced industrial evolution and industrial path diversification.

3.2 The Petrochemical Industry in Korea

The history of the petrochemical industry in Korea is well described in, "*The world created by petrochemical material: Understanding about the petrochemical industry,*" published by Korea Petrochemical Industry Association (KPIA) in 2006. The literature explains the history of the petrochemical industry in Korea as follows. The history goes back to the 1960s. The first 5-year Economic Development Plan (1962-1966) aimed to develop light industry first, so there was a necessity to develop the petrochemical industry in order to supply basic industrial materials for light industry. This demand was reflected in the second phase of the 5-year Economic Development Plan for internalization by self-producing industrial materials. As a result, Ulsan was selected as a petrochemical industrial complex, and the construction was completed in 1970s. During the late 1980s to the middle of the 1990s, the petrochemical industry enjoyed meteoric growth with great institutional support from the state. In 1988, investment liberalization was carried out via the Petrochemical Industry Investment Guidance Plan, and this led to large scale of investment in plants and equipment. Also, in 1995, the state abolished the Petrochemical Industry Investment Rationalization Plan, which completely liberalized the new establishment, so the production greatly enlarged and the industry became export-oriented.

It is true that the industry faced a downturn because of the financial crisis at the end of the 1990s, but it is a still core industry in Korea. As of 2019, for example, according to statistical data provided by KPIA, the Korean petrochemical industry ranked 4th place, recording 9,816,000 tons of ethylene production per year. The industry produced 103 trillion Won, occupying 6.5% of the manufacturing activity, and the scale of trade was 42.6 billion dollars with 29.9 billion in profits.

3.3 Ulsan-Mipo National Industrial Complex (UMNIC)

A comprehensive bibliography of Korean Industry published by KICOX in 2016 offers an excellent overview of UMNIC as follows. UMNIC is the very first and oldest national industrial complex located across Nam-gu, Buk-gu, and Dong-gu in Ulsan Metropolitan City. The central government aimed to foster development of the heavy chemical industry by specializing in several sectors such as petroleum refinement, petrochemical, automobile, and shipbuilding.

Ulsan Metropolitan City was selected as a place for the petrochemical industrial complex in accordance with a 5-year Economic Development Plan, and in 1962, the industrial complex was constructed in earnest starting with the groundbreaking ceremony of the Ulsan Industrial Center. Between 1972 and 1976, the automobile industry and shipbuilding industry were added to the industrial complex.

UMNIC has great industrial infrastructures. Together with its physical geographical traits - for example, it is a coastal city, the port has made UMNIC very competitive in imports of raw materials and exports of finished products. In addition to the port, traffic systems such as expressways, railways, and an airport are well constructed and connect the complex successfully with other regions. Additionally, there are several supporting organizations in the complex, namely

KICOX, Ulsan Economic Promotion Agency (UEPA), and Korea SMEs and Startup Agency (KOSME) in order to coordinate industrial activities there. In addition to the infrastructures directly related to industrial activities, Ulsan has a great educational foundation. A lot of schools such as universities and technical colleges are located in Ulsan, and these schools provide R&D services and foster industrial manpower to the industrial complex nearby. With these industrial infrastructures, Ulsan has performed in the highest capacity in terms of economic activities in supporting the regional economy and building a science belt connecting Busan and Pohang which occupies of 16% of Korea's national production (KICOX, 2016).

According to data from 'Factory On' run by the Korea Industrial Complex Corporation (KICOX), as of September, 2020, there are 591 enterprises in the industrial complex over an area of $45{,}594m^2$ (Unit: 1,000). Focusing on three major industries - petrochemical, automobile, and shipbuilding, the industrial complex has shown the greatest economic performance among all industrial complexes in Korea with 116 trillion Won worth of production, 48.2 billion dollars in trade, and 92,144 jobs supplied in 2018 (KICOX, 2019).

4. Case Study of the Petrochemical Industry in the UMNIC

This chapter presents 4.1) the three research questions (RQs hereafter), 4.2) an explanation of the data and methodology, 4.3) results, and 4.4) analysis and discussion.

4.1. Research Questions (RQs)

In order to examine green growth and evolutionary processes of the petrochemical industry in the UMNIC, and the industrial symbiosis from an EEG perspective, three RQs are included in this research to figure them out. The RQs are as follows.

RQ1 seeks to ascertain whether evolutionary processes in the UMNIC can be characterized by path-dependence, creation, or diversification. First, as described in the theory and background sections, the industrial characteristics of the petrochemical industry correspond to technological lock-in and use of economies of agglomeration externalities which may be correlated to path dependence (Martin & Sunley, 2006), Second, the petrochemical industry may have developed new green-related business, products, processes, or technology and this development can be included in green path creation, which refers to, "the rise of totally new green industries" (Trippl et al., 2019). Third, path diversification is a firm-level process where externalities may be engaged at multiple spatial scales (Binz et al., 2016; Grillitch & Asheim, 2018). Given the characteristics of the petrochemical industry in the UMNIC, it may not be easy to engage in path creation, but there may be path diversification in this regard.

RQ 1: Can green industrial evolution in the UMNIC be characterized by path-dependence, -creation, or –diversification?

Path develops from various sources. As state previously, path dependence is attributed to technological lock-in and economies of agglomeration externalities (Martin & Sunley, 2006), path creation can be resulted from new knowledge from innovative activities (Tripple, Grillitsch, & Isaksen, 2018), and path diversification mainly comes from the existing assets such as the combination of new and existing knowledge by networks (Trippl et al., 2019). Further, the impetus for each path development might be either endogenous or exogenous. A new path, for example, can also be generated from *within* a firm. It is possible for firms to have industrial innovation through their own R&D activities, and this innovation comes with structural changes within the firms (e.g. product or processes innovation) (Cohen & Klepper, 1996). In terms of green growth and the UMNIC, Korea may be pursuing what Martin (2012, 13) considers a 'resiliency agenda', because the country is taking action in order to generate new growth paths based on a 'self-organized criticality' (Martin and Sunley 2007), in this case related to a need to re-orient the economy toward green growth. In terms of policy prescriptions, it may also therefore prove useful to know of any impediments associated with firm-level green growth-oriented pathways.

RQ 2(a): To what extent is the impetus for green growth connected to the industrial complex endogenous or exogenous in nature?

RQ2(b): What are firm-level perceptions regarding impediments to green growth-oriented activity at the UMNIC?

Restated here for convenience, according to Chertow (2007, p.12), industrial symbiosis can be defined as, "physical exchange of materials, energy, water, and by-products among diversified clusters of firms." RQ 3 looks to tie in any possible benefits from symbiosis to EEG and a geographical perspective in order to better understand any synergies between industrial symbiosis and paths (dependence, diversification, or creation), and how industrial symbiosis is conducted at various spatial scales as well as between which actors (both within and outside of UMNIC).

RQ 3: To what extent have companies benefited from industrial symbiosis? (financially or environmentally) within the complex or at varying spatial scales?

4.2 Data and Methodology

General data such as a list of firms in the industrial complex, their sizes, and contact information was supplied by a website, 'Factory On', which is in turn operated by KICOX. KICOX coordinates industrial activities of industrial complexes in Korea. Factory On provides analysis of the surrounding environment, basic locational information, and both inner- and outer-industrial complex with any firms that would like to build a factory within a complex.

The database consisted of 591 firms in UMNIC in total. Narrowing the data down to the petrochemical industry, 42 petrochemical firms consisting of 10 of large firms, 17 medium- size firms, and 15 small-size firms located in the complex remained. There were some cases of overlapping counts and of firms having shut down. Excluding those cases, the number of viable firms decreased to 32.

Therefore, 32 questionnaires were distributed to environmental-related technology specialists or senior management staff from the department of environment and safety from October 27, 2020, to November 16, 2020. The author initially contacted each firm by phone and asked if they would respond to a questionnaire distribution. If the respondents agreed, the questionnaires were sent out. Completed questionnaires were retrieved online.

In all, a total 32 questionnaires were issued to the available firms and 19 were retrieved leading to a 59.375% initial overall response rate. However, two of the 19 responses were largely incomplete, so they were excluded from the data analysis. This led to a final response rate of 53.125%.

The questionnaire consisted of four pages, and included sections on basic company background information (product classification, age, number of employees, sales, investment in green tech); motivations for green-growth activity; location and use of external technical support; outcomes of green innovation activities; impediments to green-growth industrial activity; industrial symbiosis (resource sharing activities and partners).

The questionnaire was created in Korean. An English version was created to ensure ease of understanding and that the major thrust of each questions conformed to the goals of the research. This resulted in some minor changes being made to the Korean version, which was then distributed to a small sample of five firms. These firms indicated no confusion with the question meaning or intent. As such, the finalized survey was distributed to the remaining firms in the database.

The methodology deployed is quantitative, though supplemented by industry information where applicable. The questionnaire was designed so that the RQs could be addressed via the use of basic descriptive statistics, but in order to add depth and breadth to some of the analyses, non-parametric Mann-Whitney U and Kendall's Tau B tests are also deployed.

4.3 Results and Analysis

In this section, general descriptive statistics concerning participating firms are given. After the descriptive statistics are provided, analysis connected to each of the RQs and related discussion are provided sequentially. Before continuing, it is necessary to state in advance that all of the multi-question sections were subjected to tests of reliability, with all sections registering Chronbach's Alpha values of over 0.70.

Table 2 shows general statistical information about the respondent firms. The firms have been engaged in the petrochemical industry about 41.20 years on average. When it comes to scale, the average number of employees is 619.12, with sales of 45.81 (Unit 100 billion Won) on average, both of which are somewhat large. This is a reflection of a characteristic of the petrochemical industry in that the industry is highly capital- and technology-intensive (Nam, 2015), so they need to take advantage of economies of scale. The average investment rate is also noticeable. Compared to the global average rate in R&D by 3% of sales (Yeon, 2020), the petrochemical firms invest about 5% of their annual sales

Table 2 – Descriptive Statistics: Respondent Firm

	Age (N=15)	Employee (N=17)	Sales (N=14) (100 Billion Won)	Invest_Green (N=9)
Mean	41.20	619.12	45.81	0.05
SD	16.67	944.70	97.05	0.06

Source: Author's questionnaire (Q4-Q7 and see appendix III for the full names of the variables.)

RQ 1. Can green industrial evolution in the UMNIC be characterized by path-dependence, -creation, and –diversification?

Firms were asked to indicate the importance of five green-growth activities on Likert scales of 1 to 7. This question was asked in order to figure out what kinds of green growth-oriented activities are important for the firms. Table 3 gives the results. According to the table, the most important green growth-oriented activity of the firms is harmful substances reduction with a mean of 6.53 and a standard deviation of 0.50. While all activities are ranked over and above 4.0, and are therefore considered important, they place more emphasis on harmful substance reduction for their green growth-oriented activity. As Chertow (2007) suggests, these firms can benefit from industrial symbiosis, a topic which will be addressed soon. Correlation analysis (Kendall's Tau B) between these five variables indicates a correlation of 0.423 (significant at the 0.05 level) between purchase of environmental-friendly raw materials and green innovation capability intensification. It seems that because of the increase in capability of green innovation capability, there would be more chance that new environmental-friendly raw materials are introduced into the markets. As we shall see, this is an important consideration for industrial symbiosis.

Table 3 – The Importance of the Firms' Green Growth-Oriented Activities

	Harm_Reduce (N=17)	Green_Innov (N=17)	Purify (N=17)	Env_Edu (N=17)	Raw_Mat (N=17)
Mean	6.53	5.35	5.53	6.00	5.29
SD	0.50	1.41	1.33	0.97	1.23

Source: Author's questionnaire (Q8 and see appendix III for the full names of the variables.)

Next, a Mann-Whitney U Test is deployed to examine whether there are differences in means between firms with varying outcomes of green growth innovative activity vis-à-vis use of external support. The rationale for this test is that the outcomes will help to assess path types, but the comparison of means sheds more light on specificities associated with certain outcomes.

According to the results (see Table 4), there are some relationships identified. First of all, it is necessary to look at a case of path creation. A new entry to green-related business (New_Busi), new launch of green-oriented industrial process (New_Products), and new development of green technology (New_Tech) have one thing in common, path creation (Binz et al., 2016). All of these are the cases of path creation. According to the analysis, firm use of research consortia (Consortia, 0.0038), university research (RD_Uni, 0.043), and industry associationions (Associate, 0.019) are statistically different for those who have a new entry to green-related business, who have a new launch of green-oriented products, and who have a new development of green technology respectively compared to those who do not have those. These results demonstrate there are cases of green path creation among those variables and the most influencing factor for the path creation is inflow of new knowledge and external sources for innovation.

Trippl, Grillitsch, and Isaksen (2018) and Isaksen and Trippl (2017) argue in common that individual and organizational actors are great sources of information and knowledge carriers from outside, and that the information and knowledge will be a foundation for innovation activities which will bring about new path development. In this sense, this is where all of the research consortia, university research and industrial associations figure in. To begin with, both research consortia and university research are knowledge suppliers rather than knowledge consumers, and even though the role of industrial associations as knowledge suppliers is not that strong, KPIA, the umbrella organization for the industry, does participate in and disseminate industrial and technological strategy research. Also, KPIA makes connects petrochemical firms by presenting space for information exchange. Binz et al. (2016) also place emphasis on the significance of external linkages for new path creation, and this is where KPIA potentially plays a role for the petrochemical firms in the UMNIC. In sum, research consortia (Consortia), university research (RD_Uni), and industrial associations (Associate) function as knowledge suppliers, and provide new knowledge from outside of the UMNIC to the petrochemical firms. KPIA is partially connected to this process. Together, the newly imported knowledge has developed new green paths such as a new entry to green-related business (New_Busi), the new launch of green-oriented products (New_Product), and the new development of green technology (New_Tech).

Table 4 Mann & Whitney U Test: Green Growth Outcomes and External Service Use

Sectors	U Statistics	Yes or No (Mean, SD)
New_Busi	Consortia (0.038)	Y (6.00, 0.00)
		N (3.73, 1.74)
New_Product	RD_Uni (0.043)	Y (5.17, 2.14)
		N (3.50, 1.31)
New_Tech	Associate (0.019)	Y (7.00, 0.00)
		N (4.31, 1.65)
Green Diversify	Networks (0.042)	Y (3.00, 1.41)
		N (4.67, 1.00)
Green_Improve	RD_Uni (0.044)	Y (3.83, 1.70)
		N (6.50, 0.71)

Source: Author's questionnaire (Q9 and Q11)

Firms were also asked to rate to what extent their own R&D center benefits their green growth activities on a Likert scale of 1 to 7 to identify the role of in-house R&D. The mean of the response is 5.29 with the standard deviation of 1.49, so their in-house R&D centers are making contributions to their green growth activities. Putting it differently, as suggested above, their in-house R&D centers are involved in creating knowledge and technology, which has potential to lay the foundations for green innovation. Implications for the augmentation of intra-firm R&D activity with extra-firm services will be addressed in connection to the second RQ.

Table 5 The Importance of Company's Own R&D Center for Green Growth Activity

	RD_Own
Mean	5.29
SD	1.49

Source: Author's questionnaires (Q10 and see appendix III for the full names of the variables); n=17

When it comes to green innovation activities, firms were asked to choose among the following: 1) new entry to green-related business, 2) new development of green-oriented industrial process, 3) new launch of green-oriented products, 4) new development of green technology, 5) establishment of an affiliated or spinoffs firms based on green technology, 6) diversification of the existing business, processes, technology, or products, and 7) improvement of the existing business, processes, technology, or products to investigate their type of path development. This question allowed multiple responses if they have more than one outcome. From a perspective of frequency, improvement of the existing business, processes, technology, or products reached the highest frequency (Green_Improve, 13) followed by new launch of green-oriented products (New_Product, 7) and diversification of the existing business, processes, technology, or products (Green_Diversify, 6). However, none of the responding firms have established any affiliated or spinoffs firms (Green_Spinoff, 0) based on green technology. This stands in contrast to EEG theorizing, which envisions spinoffs as a key mode of path dependency or diversification (Boschma & Frenken, 2006).

Table 6 Outcomes of Green Growth Activities

	New_ Busi	New- Process	New_ Product	New_ Tech	Green_ Spinoff	Green_ Diversify	Green_ Improve
Frequ ency	4	3	7	2	0	6	13

Source: Author's questionnaire (Q11 and see appendix III for the full names of the variables.)

Next, given the implications for path diversification that may stem from the use of external support (Binz, et al. 2006; Grillitch & Ashiem, 2018), firms were asked the extent to which 15 external actors, divided into private, public, and other services (following MacPherson, 1997) benefited their green growth activities on 7-point Likert scales. Following Arndt and Sternberg (2000), and later Gress (2015), firms were also asked to indicate the location (within the complex, in another region, or abroad) of each of these external services used. Before proceeding, it is important to note that Mann-Whitney U tests revealed no difference depending on whether or not firms were SMEs or large firms for any of the response categories. It is interesting to note that all of the external sources of knowledge or assistance were ranked by firms at the midway 4.0 range or higher, lending some evidence that firms are pursuing path diversification. Among private services, management support and consulting services (Consult, 5.35) ranked the highest for green growth innovation activity. In a similar way, government supports (Gov_Help, 5.82), namely either financial, or institutional support, are the key factors for green growth innovation with the public sector.

Informal business networks (networks, 3.00) were identified by firms statistically as less important for those who a have diversification of the existing business, processes, technology, or products (0.042). This is contrary to work of Grillitsch and Asheim (2018) who recognize the impact of networks for path diversification. In this case of the present research, because the questionnaire deals with *informal* networks, it is necessary to distinguish *formal* and *informal* networks. Cases of networks in the present research take a formal form of networks because those are the networks between official institutions such as private R&D centers, universities, or government, and knowledge from those institutions has been confirmed to contribute to path development. The questionnaire, however, only *asks* for input on the role of *informal* networks, so there may be difference between the functions of formal and informal networks. For example, Allen, James, and Gamlen (2007) argue that informal networks exert power in terms of knowledge exchange and dissemination. In contrast to this, knowledge from formal networks has been identified as a great source for innovation leading to path development. In conclusion, informal business networks (Networks) can contribute to spread and movement of knowledge, but it is formal networks which are stronger in terms of having impacts on path development itself.

Last, there is a statistical significance in the role of university research (RD_Uni, 0.044) between for those who have an improvement of the existing business, processes, technology, or products (Green_Improve) and those firms who do not. There are two reasons for this. First, akin to Martin and Sunley's (2006) argument of technological lock-in, petrochemical firms in UMNIC also experience lock-in. As suggested above, the petrochemical firms in UMNIC have 41.20 years of industrial age on average. During the period, the petrochemical firms have constructed great industrial infrastructures, and the UMNIC has evolved into a systematic, integrated, and agglomerated industrial complex that has entered a mature state (Nam, 2015). Therefore, the petrochemical industry has reached a certain level of technological development, so it is challenging to further develop or deviate from this level (Nam, 2015). This is where technological lock-in comes into being, because characteristics of the petrochemical industry, such as large sunk costs, infrastructures, and capital, correspond to the conditions for technological lock-in proposed by Martin and Sunley (2006). Hence, the petrochemical firms tend to depend on the current industry system, and this hinders the firms' attempts to deviate from the lock-in trajectory. Accordingly, new knowledge supply is used to develop a new path, rather than used to improve the existing industry system.

When taking the geographical of location of the services into account, the locational relationship of all categories of services, except customers, is concentrated in the same region. In contrast, locational relationships abroad have relatively lower values ranging from 11 to 20 compared to those of same region (a range from 18 to 37). This may be because of related variety spillover effects accentuated by geographical proximity (see Boschma & Frenken, 2011), so the shorter the physical distance they have, the more intense the location relationships between the petrochemical firms and these diversified services.

There is an interesting result about the relationship between customers, suppliers, and competitors in the petrochemical industry. Their values are relatively greater than the others and their locational relationships are evenly distributed across the regions, even including abroad. This can be explained by the characteristics of petrochemical industry in that the industry is not only highly systematic and vertically integrated as a production chain-type, but also is export-oriented (Nam, 2015). Other factors such as informal business networks (Networks), industrial association (Associate), academic conference (Conference), and purchase of green technology (Buy-Tech), and external factors (External) which are not part of the production chain-type have relatively lower values. Thus, it is possible to infer that relationships between actors within a similar production chain-type are regarded more significant than the relationships outside of the production chain-type in terms of green growth innovation activity of the petrochemical firms in the UMNIC. This, at least in part, is confirmation of the technological relatedness and related variety thesis espoused by EEG (Boschma & Frenken, 2011).

Table 7 – Sources and Location of Outside Knowledge for Green Growth Innovation Activities

	Importance		**Locational Sum**		
Private Services	Mean	SD	Same region	Other region	Abroad
RD_Priv	4.71	1.53	36	22	16
Consult	5.35	1.06	34	23	13
Testing	4.50	1.55	28	18	14
Public Services					
RD_Uni	4.13	1.82	28	19	14
RD_Gov	5.00	1.59	27	21	14
Gov_Help	5.82	1.47	35	25	13
Consortia	4.19	1.83	27	21	14
Other Factors					
Customers	5.94	1.14	37	29	29
Suppliers	5.41	1.77	35	28	24
Competitors	5.35	1.66	33	26	24
Networks	4.00	1.59	22	16	15
Associate	4.65	1.90	22	14	11
Conference	4.31	1.78	18	13	11
Buy_Tech	4.50	1.55	19	13	11
External	4.31	1.62	19	13	11

Source: Author's questionnaire (Q9 and see appendix III for the full names of the variables; service categories originally adapted from MacPherson, 1997 and later Gress, 2015)

RQ 2(a): To what extent is the impetus for green growth connected to the industrial complex endogenous or exogenous in nature?

In addition to the answer for RQ 1, RQ 2(a) can also be answered by networks which connect the firms with other actors in the UMNIC. It has been identified that external sources, especially new knowledge inflow, exert great power on path development such as path creation and path diversification (Isaksen & Jakobsen, 2017) and these processes are facilitated by the role of networks (Grillitsch, 2016) because networks provides space to combine, exchange, and interchange knowledge and resources (Grillitsch & Asheim, 2018). So to speak, for the petrochemical firms which suffer from technological lock-in, networks can infuse new life into the firms by connecting them with external actors, especially research-related, and the relationship formed by this process is a trigger of green evolution in the UMNIC.

It is true that the firms responded that their in-house R&D centers were useful for their green growth-oriented activities (see Table 5) because they might have capability to some extent to innovate by themselves. However, as Table 8 shows, there are correlations between in-house R&D and knowledge suppliers, namely, university research (RD_Uni, 0.561), government R&D (RD_Gov, 0.416), and consortia (Consortia, 0.612). This implies that green evolution in the UMNIC has been driven in tandem by intra-firm activity and by collaboration or cooperation among inter- and extra-firms networks which are parts of endogenous factors. Bathelt et al. (2004) also support this fact by arguing that aggregation of firm local networking and various external linkages function as a catalyst triggering innovation, and that this innovation is the asset for green growth path development. Exogenous factors such as climate change and Korea's commitment to the reduction of greenhouse gases also exist, and these may impact how the firms run their business, for example, based on Corporate Social Responsibility (CSR) or social contributions, but, from the perspective of EEG, endogenous factors, primarily networks relationships, are more dominant in terms of triggering path development for green growth. This, in turn, corresponds to the tendency of EEG to focus on endogenous factors (see Tripple et al., 2018).

Prior research has suggested that in-house R&D success is accentuated by a consistent search for new external sources of knowledge (Henriksen, 2001). This study addresses the process of problem-solving that engineers face and how they acquire and disseminate knowledge from the outside of their firms to solve the problem they have. For example, when they face a certain problem, they start searching sources of knowledge, and in this sense, knowledge exchange with experts may provide opportunities for the engineers to figure out the problem (Henriksen, 2001).

In a similar way to the argument by Henriksen (2001), new external sources of knowledge can be beneficial for the petrochemical firms in the present research. As Table 8 suggests, in-house R&D is correlated to private R&D (RD_Priv, 0.500), university research (RD_Uni, 0.561), government R&D (RD_Gov, 0.461), and research consortia (Consortia, 0.612), all of which are organizations for new knowledge creation. These correlations suggest that that there are networks constructed among those variables and based on the networks, knowledge can be created, disseminated, and exchanged. In the case of the present research, the enrollment rate for the KPIA is approximately 58%, and two of the core functions of KPIA are providing both a space for knowledge and information exchange, and to gather and disseminate the most recent information about the petrochemical industry in general. Thus, in the networks facilitated by KPIA, new knowledge from outside of the firms can flow into the firms with competency in innovative capacity (Isaksen & Trippl, 2017; Grillitsch & Isaksen, 2018). Further, knowledge is exchanged and disseminated along the networks, so these processes bring about potential for green growth innovation, and the petrochemical firms can benefit from the newly combined knowledge for their green growth activities.

Table 8 Correlation between In-house R&D and External Knowledge Sources

	RD_Priv	Consult	Testing	RD_Uni	RD_Gov	Consortia	Buy_Tech	RD_Own
RD_Priv	1	.488*	0.270	0.365	0.384	0.315	-0.207	.500*
Consult		1	0.145	0.172	.477*	0.295	0.207	0.375
Testing			1	.416*	0.109	.427*	.554**	0.366
RD_Uni				1	.474*	.787**	0.271	.561**
RD_Gov					1	.554**	0.099	.416*
Consortia						1	0.301	.612**
Buy_Tech							1	0.327
RD_Own								1

Source: Author's questionnaire (See appendix III for the full names of the variables.)

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed)

RQ 2(b): What are firm-level perceptions regarding impediments to green growth-oriented activity at the UMNIC?

The firms were asked to rate to what extent the variables in Q12 disrupt green growth activity on Likert scales of 1 to 7 to identify barriers for green growth activities. According to the responses, paperwork for administration services and approval processes (Paperwork) were identified as the most serious barriers to firm-level green growth-oriented activity. In addition to this, fees for private external services (Fees, 5.12) are also strong barriers. Private technical services has the lowest mean (Services, 3.53) and the second lowest standard deviation (1.01). This infers that private technical services are beneficial, but their fees matter for their green growth-oriented activities. In addition to the private technical services

(Services), a lack of information available about relevant industry associations and academic conferences (Lack_Info) has the second lowest mean (3.94) and a relatively lower standard deviation (1.09). This implies that the firms take advantage of information or knowledge from the association and the conference for their green growth-oriented activities, though recognize that more information about these would be welcomed.

Again, results suggest that difficulty related to paperwork and approval of public services is the biggest barrier for green growth-oriented activity. This phenomenon may be attributed to inefficient public administrative services of the Korean government. Sung (2004) points out that Korean public administrative services are supplier-centered, rather than customer-centered, so it exposes a lot of problems and limitations, especially inefficiency when it comes to services for customers. The reason that difficulty of paperwork and approval of public services were chosen as the biggest issues may be inferred in this sense. Domestic green industrial activities are highly under the purview of regulations such as environmental laws because the firms have to satisfy the relevant criteria. There are therefore a lot of cases in which firms must contact public administrative institutions. In spite of this fact, inefficient public administrative services may discourage the activities for green growth. Thus, there is a necessity to transform the current state of public administrative services into more customer-centered. At least one author has suggest that this may be accomplished via five concepts - reactivity, convenience, quickness, accuracy, and fairness (Park, 1996).

In addition to the barriers, according to Table 9, private technical services (services, 3.53, 1.01) and lack of information available about industry association and academic conference (Lack_Info, 3.94, 1.13) are regarded as the two weakest impediments for green growth-oriented activity, the values of which are lower than the average of 4.00. In case of the samples of the present research, about 58% of the samples are members of KPIA and the core functions of KPIA. This means that the majority of the firms are well aware of relevant organizations and that the members are enjoying opportunities to interact with those organizations. Still, as related earlier, firm ratings of near the midway point of 4.0 suggest that a better job could be done insofar as communicating these services to the universe of firms in the complex.

Furthermore, private technical services (Services) recorded the lowest value (3.53) because the private technical services are actually beneficial for the firms in the UMNIC. Green evolution in the UMNIC proceeds like a domino. To be more specific, geographical proximity helps to form trust and cooperation between the related actors in the same region (Jensen, et al., 2011), and based on the trust and cooperation, networks develop. These networks in turn serve to connect the actors (Grillitsch, 2016) by providing more chances to combine and exchange local knowledge and local assets (Grillitsch & Asheim, 2018). In addition to this, new knowledge from external sources, external private organizations, such as private, university, and government research institutions in this case, are able to infuse new knowledge, technology, external sources (Isaksen & Trippl, 2017) in order to make the firms in the UMNIC more capable of innovating and engaging in their green growth-oriented industrial activities. Meanwhile, it has been confirmed in the present research that the birth of new knowledge or combination of new knowledge with the existing resources have developed green innovation capabilities of the firms to green their industrial activities.

Table 9 - Barriers for Green Growth-Oriented Activities

	Fees	Services	Info	Paperwork	Lack_Info	Lack_Know	Tech_Help	Tech_Distance
Mean	5.12	3.53	4.76	5.18	3.94	4.88	4.59	4.35
SD	1.17	1.01	0.97	1.13	1.09	1.22	1.46	1.50

Source: Author's questionnaires (Q12 and see appendix III for the full names of the variables.); n=17

RQ 3: To what extent have companies benefited from industrial symbiosis? (financially or environmentally) within the complex or at varying spatial scales?

The reason that industrial symbiosis is getting popularity in a region is that having industrial symbiosis is beneficial for the firms' industrial activities (Chertow, 2007). Based on the review of the literature, firms were asked to rate the extent to which resource sharing, or industrial symbiosis, is beneficial for their business on a Likert scale of 1 to 7. The mean response was 5.18 and the standard deviation was 1.38. Even though there are two small values of 2 and of 3, the overall values are greater than 5, so it is reasonable to estimate that firms view industrial symbiosis in the form of resource-sharing as beneficial for their green growth-oriented business activity.

Table 10 The Importance of Resource-Sharing (Industrial Symbiosis) for Business

	Share_Benefit
Mean	5.18
SD	1.38

Source: Author's questionnaire (Q14 and see appendix III for the full names of the variables.); n=17

To plumb this concept a bit deeper, the firms were also asked to what degree and what kinds of resource-sharing activities are important for their business to distinguish the roles of each sharing activity. The firms generally perceive both infrastructural and material resources-sharing (Infra_Share, 6.12) and human resource-sharing (HR_Share, 6.12) such as labor, wages, and knowledge as equally the most important aspects of industrial symbiosis in the UMNIC. However, institutional endowments (Rules_Share, 5.47), while important, are relatively less significant and have a larger standard deviation (1.42). This means that institutional endowments may be beneficial for some firms and not that beneficial for the others.

Table 11 The Importance of Resource Sharing (Industrial Symbiosis) by Type

	Resource_Share	Infra_Share	Tech_Share	HR_Share	Rules_Share
Mean	5.65	6.12	5.82	6.12	5.47
SD	1.54	1.05	1.24	1.05	1.42

Source: Author's questionnaire (Q15 and see appendix III for the full names of the variables.); n=17

As Table 11 presents, the two most important parts of resource-sharing are sharing of-industrial resource and human resource, which have the highest mean and the lowest standard deviation, so it seems that there in some agreement with respect to the degree of the importance of those among the respondent firms. Table 12 also supports this relationship. As Table 12 suggests, there is a strong correlation (0.842) between industrial resources sharing (Tech_Share) and human resource sharing (HR_Share). This correlation confirms that the benefits from those two activities are the largest and the reason is attributed to externalities resulted from economies of agglomeration as suggested by Martin and Sunley (2006).

The UMNIC has evolved into a specialized cluster for the petrochemical industry over a long time. In this regard, it is experiencing integrated processes that the petrochemical firms located in the cluster can avail themselves of (Nam, 2015). As the UMNIC has evolved into a petrochemical cluster, there are many factors such as skilled labor, knowledge, and technology (Chertow, 2007) that are highly associated with the industry. Not only independent firm industrial activities, but also the combination of those factors help create synergistic possibility (Chertow,

2004) that further develops agglomeration benefits. Skilled labors in the cluster can carry new knowledge and sources from outside (Trippl, Grillitsch, & Isaksen, 2018; Isaksen & Trippl, 2017) and the new knowledge and sources are combined and develop into a practical technology which leads to path development such as path creation and path diversification, and in the case of the present research, industrial symbiosis in the cluster. In other words, externalities are generated through the agglomeration of industrial resource and human resources, and the externalities result in green evolution. As a result, the petrochemical firms in the complex have constructed a form of 'contractual dependence' (Jacobsen, 2006) in forming a relationship for resource-sharing.

In addition to agglomeration benefits, geographical proximity contributes to the formation of industrial symbiosis because it helps develop trust and cooperation between the actors (see Hewes & Lyons, 2008). In addition to economic and practical benefits of local cooperative industrial activities, those two institutional factors are required for industrial symbiosis. That is because there are some cases in which the firms may need to disclose and share their production processes, and without them, firms are reluctant to expose and connect their industrial processes to other firms (Gibbs, 2003). In this sense, trust and cooperation make the firms overcome these barriers in facilitating industrial symbiosis.

Table 12 Correlations: Importance to Resource Sharing by Motivation and Support

	Resource_Share	Infra_Share	Tech_Share	HR_Share	Rules_Share	Gov_Support	Costs	Ethic
Resource_Share	1	0.216	0.350	0.374	-0.135	0.321	.572*	-0.156
Infra_Share		1	0.463	0.362	0.042	0.429	0.144	0.337
Tech_Share			1	.842**	0.041	0.061	0.041	-0.063
HR_Share				1	0.042	-0.082	0.103	-0.042
Rules_Share					1	0.200	-0.263	0.474
Gov_Support						1	0.257	0.303
Costs							1	0.000
Ethic								1

Source: Author's Questionnaire (Q15 and Q16 and see appendix III for the full names of the variables);

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 13 Geographical Location of the Relationship of Industrial Symbiosis

	Share_Same	Share_Other	Share Abroad
Frequency	15	6	2

Source: Author's questionnaires (Q13 and see appendix III for the full names of the variables.)

Then what are the motives to develop industrial symbiosis for the petrochemical firms? On 7-point Likert scales, firms were asked to indicate to what extent their motivation for industrial symbiosis was characterized by four different aspects. The firms responded that government support (Gov_Support, 6.24) such as financial supports, subsidy, institutional, or regulations are the most critical factor for forming resource-sharing relationships, followed by cost motivation (Costs, 6.00) like cost reduction in waste management or by-products. Business ethics, CSR or social contribution, for example, (Ethic, 5.76) scores greater than the average, so all of the factors listed accelerate the formation of symbiotic relationships. There was only one firm that responded "Other", but the firm did not specify what the other factor was, so that response was excluded from data analysis.

Table 14 – The Importance for Forming the Relationship of Industrial Symbiosis

	Gov_Support (N=17)	Costs (N=17)	Ethic (N=17)	Other (N=1)
Mean	6.24	6.00	5.76	N/A
SD	1.09	1.00	1.15	N/A

Source: Author's questionnaires (Q16 and see appendix III for the full names of the variables.)

Table 15 shows Kendall's Tau B correlations between variables in Q8 (green growth activities) and Q16 (industrial symbiosis-related variables). Ethics, represented as CSR or social contribution, have correlation with five variables. This is most probably because the roles of firms have increased compared to the past.

These days, Jones (1980) argues that firms have to break away from mere law-based, contractual relationships, and be more cognizant of their obligation to society. Additionally, Chun and Kim (2011) suggest that firms have to pay attention to the local community in addition to their shareholders, customers, staff, suppliers, and buyers. Because of the changes in the roles of firms, firms these days may be contributing more for green growth activity via green innovation capability intensification (Green_Innov), environment purification activity (Purify), environment education (Env_Edu), and the purchase of environmental-friendly raw materials (Raw_Mat).

There is one more correlation (0.49) the cost motive (Costs) and harmful substance reduction (Harm_Reduce). With the relationship of industrial symbiosis, waste and by-products are transacted among firms, so it is possible for the firms to reduce costs for waste management and emission of harmful substance at the same time. This may help to explain the positive correlation between these two variables.

Table 15 Correlations: Green Growth and Industrial Symbiotic Activity

	Harm_Reduce	Green_Innov	Purify	Env_Edu	Raw_Mat
Ethic		0.65 (0.00)	0.74 (0.00)	0.69 (0.00)	0.63 (0.00)
Costs	0.49 (0.033)				

Source: Author’s questionnaire (Q 8 and Q16 and see appendix III for the full names of the variables.)S

Adding to the above, as Yu, Han, and Cui (2015) and Park et al. (2008) argue, industrial symbiosis is mainly driven by economic motivation. As the definition of industrial symbiosis, “…physical exchange of materials, energy, water and by-products” (Chertow, 2007, p.12) suggests, industrial symbiosis is a recently developed alternative for waste disposal, so a certain waste of a firm can become a precious industrial resource for another firm, and during this exchange, income arises. Inferring from the correlation (0.572) between cost motive (Costs) and natural resources (Resource_Share), a decrease in production costs resulted from natural resources sharing may be a great benefit of industrial symbiosis. Resource-sharing is under the influence of geographical proximity. More specifically, if geographical proximity is not guaranteed, there would be additional costs for transportation of natural resources or by-products and, in case of heat or steam, there would be loss, so efficient transaction would not take place. In short, Weberian location theory is still largely applicable to the present case.

Having said this, according to Table 9, industrial symbiosis often takes place within the same region, but it sometimes occurs with other regions or reaches to other countries. The reason for intra-region industrial symbiosis is attributed to, as suggested at the above, agglomeration benefits. In the case of inter-region industrial symbiosis, it may be related to other production-related actors, but it is necessary to take administrative actors such as Korea National Clean Production Center (KNCPC), Korea Water Resources Corporation (KOWACO), or KICOX into account (Park et al., 2008) because they are in charge of providing and coordinating administrative services for the firms in terms of industrial symbiosis. Thus, it can be said that intra-region industrial symbiosis is more about industrial activities and inter-region industrial symbiosis may be related to administration, so industrial symbiosis takes a different form depending on a spatial scale.

5. Conclusion

5.1 Summary

The present research explored the green-oriented evolution of petrochemical firms in the UMNIC by deploying an EEG framework inclusive of institutional and industrial symbiosis considerations. There are several existing research pieces about Eco-Industrial Parks (EIP), but these tend to be broad perspectives rather than detailed. Given the importance of green growth to Korea going forward, the longstanding importance of the petrochemical industry to Korea's economic health, and a decided dearth of EEG-based work on this topic, petrochemical firms in the UMNIC were chosen for analysis.

The major findings are as follows. First, the green evolution of the petrochemical firms in the UMNIC can be characterized by path-creation, diversification, and dependence, rather than by one all-encompassing norm. New knowledge inflow supplied by networks becomes a foundation for innovation, and the innovation is a strong impetus triggering new paths, namely new green-business, products, and technology. However, because of the embedded industrial infrastructure that the petrochemical firms have constructed over a long period of time, there is a degree of technological lock-in. As such, despite any inflow of new knowledge, the existing industrial ecosystem is not easily affected and shows sign of path dependency. In other words, knowledge is used for the propagation of new, green-related activity, rather than improving the existing system.

Second, the impetus for green growth is primarily exogenous in nature. In this sense, this refers to firm-manifested change in coordination with external support of varying types and at varying spatial scales. New knowledge from external sources was found to be a trigger for green path development. The petrochemical firms have developed relationships with external knowledge producers such as university research institutions, government research institutions, and research consortia. Based on the relationship among exogenous factors, the petrochemical firms have had green evolution and industrial symbiosis in the UMNIC.

Third, supplier-centered and public servant-centered rather than customer-centered public administration services are the most serious impediment for green evolution in the UMNIC. Even though the relationship among the petrochemical firms and government is considered important for green evolution, this administrative barrier may disrupt or discourage green-related activities going forward.

Last, in terms of industrial symbiosis, the petrochemical firms in the UMNIC take advantage of positive externalities resulted from economies of agglomeration. The UMNIC has evolved into a cluster specialized in the petrochemical industry, so much of the relevant industrial infrastructure located there have formed economies of agglomeration. Spatially, industrial symbiosis is conducted in the form of production-related relationships within the same region, but insofar as industrial symbiosis with other regions, it comes in the form of administrative relationships (e.g. government assisted) rather than firm-based, production-centered relationships.

5.2 Limitations and Implications for Future Research

The present research has two immediately apparent limitations. First of all, the sample, while fairly representative of the petrochemical firms in the complex, can be regarded small. Time and budget limitations precluded the scaling up of the research to better address this limitation. In the future, firms in one industry operating in more than one complex could be surveyed to help with this problem, or perhaps firms from multiple industries operating in one complex.

In addition to the small sample, there is the question of breadth. It was possible to account for *general* green growth-related processes at the firm level, for example, but that did not extrapolate exceptionally well to the industrial complex level. The petrochemical industry is a national core industry, so there is very limited access to exacting, perhaps proprietary information available vis-à-vis the petrochemical firms, and in truth, even the obtainable information was less detailed than the author expected. Therefore, it was difficult to shed more light on exactly what kinds of new green business, new green products, and new green technology are emerging in the UMNIC. One possible way to overcome this limitation would be to augment analyses with a wider study of multiple industrial complexes with several firm, industry, and government representatives. Another possible remedy would be to conduct a series of in-depth ethnographies.

The present research may forward the following research implications: First, the application of locational aspects to questions of green evolutionary relationships and processes would bring about additional geographical insight. In the present research, the relationships tended to be limited to intra-firm, and less so to inter-firm and extra-firm relationships. This, as was suggested, may have to do with specificities associated with this industry and conjoined agglomeration economies beneficial to industrial symbiosis. Still, as there were some firms which responded that they had a resource sharing relationship (industrial symbiosis) with other actors in other regions, or even with those abroad, further research into spatial properties and inter and extra-firm relationships would possibly offer interesting results about green evolution and industrial symbiosis.

Second, as alluded to briefly previously, future research would benefit from taking other industries into account. This could be done in a simultaneous study, or by deploying the same survey instrument and methodology via an accumulation of comparable case studies. Although the present research deals with the petrochemical industry, it is not the only industry in the UMNIC, for example. There are other major industries such as shipbuilding and automobile industries in the UMNIC. Therefore, examining the green evolution of all of those major industries together will better provide general patterns of the green evolution *of* the UMNIC because all of them have their particular and distinguished industrial processes.

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Appendix I: Survey Instrument (English)

1. Company Name:

2. Company Address:

3. What does your company primarily manufacture?

Products	Classification Number	
Coal and other basic organic petrochemicals	20111	
Coal and other organic chemicals	20119	
Synthetic rubber	20201	
Synthetic resin and other plastic materials	20202	
Fertilizers and nitrogen compounds	2031	
Germicides, insecticides and pesticides	2032	
Ink, paint, coating and similar products	2041	
Detergents, cosmetics and polishing preparations	2042	
Man-made fibers	205	
Other (Please specify):		

4. How long has your company been in business? _____Years

5. What is the number of employees at your facility in the complex? _______

6. What is the total annual sales from industrial activity inside the complex?

____Won

7. What is the percentage of investment in green growth-oriented technology to your annual sales? ______%

8. How important are the followings for your company's green growth-oriented activity?

1) Harmful substances reduction

1 (Not important) 2 3 4 5 6 7 (Very important)

2) Green innovation capability intensification

1 (Not important) 2 3 4 5 6 7 (Very important)

3) Environment purification activity (volunteer service)

1 (Not important) 2 3 4 5 6 7 (Very important)

4) Environment education

1 (Not important) 3 4 5 6 7 (Very important)

1) Purchase of environmental-friendly raw materials

1 (Not important) 2 3 4 5 6 7 (Very important)

9. To what extent have the followings benefited your company's green growth activities?

Sources of Outside Technical Support	**(A) INNOVATION**							**(B) LOCATION**											
	1=No Importance to 7Critically important							**0 = No relationships to 3 = very intense relationships**											
Private Services	**Importance to green innovation activity development**							**Within the Complex**				**Other Region**				**Abroad**			
Industrial design	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Private (contract) R&D	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Management support/consulting	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Testing services	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Public Services																			
University research	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Government R&D	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Government financial/business assistance	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Research Consortia	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3

Other Services																			
Customer firms	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Supplier firms	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Competitors	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Informal business networks	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Industry associations	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Academic converence	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
Purchase of green technology	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
External factors	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3

10. To what extent has your company's own R/D center benefited your company's green growth activities?

1 (Not at all) 2 3 4 5 6 7 (Very much)

11. What are the outcomes of company's green innovation activities?

1) New entry to green-related business
2) New development of green-oriented industrial process
3) New launch of green-oriented products
4) New development of green technology
5) Establishment of an affiliated or spin-off firms based on green technology
6) Diversification of the existing business, processes, technology, or products
7) Improvement of the existing business, processes, technology, or products

12. To what extent do you agree or disagree the following statements associated with your green growth-oriented activity?

1) Fees are too high for private external services

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

2) Private services are not technically able to help us

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

3) There is not enough information available about government-related R/D opportunities

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

4) Paperwork and approval to access public services is difficult to accomplish

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

5) There is a lack of information available about industry association and academic conference

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

6) There is a lack of knowledge and personnel continuity in our region's government R/D center

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

7) External technical help often cannot help us in a timely enough manner

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

8) External technical services are too far away from us to be helpful

1 (Very strongly disagree) 2 3 4 5 6 7 (Very strongly agree)

13. Where are the companies that share resources with your company located?

1) same region 2) other regions 3) abroad

14. To what extent is resource sharing beneficial to your company's industrial activities?

(e.g. sharing wastes, byproducts, infrastructures, or raw materials)

1 (No beneficial) 2 3 4 5 6 7 (Very beneficial)

15. To what extent are the following important to your company's resource sharing activities?

1) Natural resources

1 (Not important) 2 3 4 5 6 7 (Very important)

2) Infrastructural and material resources

1 (Not important) 2 3 4 5 6 7 (Very important)

3) Industrial resources (technology and firm competency)

1 (Not important) 2 3 4 5 6 7 (Very important)

4) Human resources (labor skills, costs, knowledge)

1 (Not important) 2 3 4 5 6 7 (Very important)

5) Institutional endowments (rules, routines, norms)

1 (Not important) 2 3 4 5 6 7 (Very important)

16. How critical are the following when forming resource-sharing relationships?

1) Government support (financial supports, subsidy, institutions, regulations)

1 (Not critical) 2 3 4 5 6 7 (Very critical)

2) Cost motive (reduction in waste management)

1 (Not critical) 2 3 4 5 6 7 (Very critical)

3) Business ethic (CSR or social contribution)

1 (Not critical) 2 3 4 5 6 7 (Very critical)

4) Other (Please specify):

1 (Not critical) 2 3 4 5 6 7 (Very critical)

This is the end of the survey. I highly appreciate for your participation.

Appendix II: Survey Instrument (Korean)

1. 회사명:

2. 회사주소:

3. 귀사의 주요 생산품목은 무엇입니까?

품목	분류 번호	
기초 유기화학 물질	20111	
석탄화학계 화합물 및 기타 기초 유기화학 물질	20119	
합성고무	20201	
합성수지 및 기타 플라스틱 물질	20202	
비료 및 질소 화합물	2031	
살균・살충제 및 농약	2032	
잉크, 페인트, 코팅제 및 유사제품 제조업	2041	
세제, 화장품 및 광택제	2042	
화학섬유	2050	
기타 (적어주십시오):		

4. 귀사는 석유화학산업에 진출한지 얼마나 되었습니까? ______년

5. 귀사(울산미포국가산업단지 내)의 직원은 총 몇 명 입니까? ______명

6. 귀사(울산미포국가산업단지 내)의 연 매출은 총 얼마입니까? ______원

7. 귀사(울산미포국가산업단지 내)는 녹색성장을 위한 기술개발에 연 매출의 어느 정도를 투자하고 계십니까? ______%

8. 아래의 표기된 요소는 귀사가 추구하는 녹색성장활동에서 얼마나 중요합니까?

1) 유해물질 배출량 감소

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요함)

2) 녹색혁신역량 강화

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요함)

3) 환경정화활동 (봉사활동 등)

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요함)

4) 환경교육

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요함)

5) 친환경 자재 구매

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요함)

9. 아래의 활동들은 귀사의 녹색성장에 관련된 활동들에 얼마나 중요합니까?

항목	(A) 혁신							(B) 관계											
	1 = 중요하지 않음 7 = 아주 중요함							**0 = 아주 밀접하지 않음 3 = 아주 밀접함**											
사설 서비스	**녹색혁신활동 발전에 미치는 중요도**							**같은 지역**				**타 지역**				**해외**			
사설 (계약) R/D	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
경영지원 및 컨설팅	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
테스트 서비스	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
공공 서비스																			
대학교 연구	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
정부 R/D	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
정부지원(재정적 지원 및 제도적 지원 등)	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
산학연	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
기타 서비스																			

고객사	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
공급사	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
경쟁사	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
비공식적 사업 네트워크	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
산업협회	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
학회	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
녹색기술 구매	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3
외생적 요소	1	2	3	4	5	6	7	0	1	2	3	0	1	2	3	0	1	2	3

10. 귀사의 자체 연구소는 녹색성장활동에 얼마나 중요합니까?

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요함)

11. 귀사의 녹색활동의 결과물은 어떤 것들이 있습니까?

1) 녹색관련 신사업 진출
2) 녹색관련 신공정 개발
3) 녹색관련 신상품 출시
4) 녹색기술 개발
5) 녹색기술에 기반하여 자회사 또는 스핀오프 회사 설립
6) 기존 사업, 공정, 기술 및 상품의 다각화
7) 기존 사업, 공정, 기술 및 제품의 개선

12. 귀사의 녹색성장활동에 관련하여, 하기에 서술된 내용에 얼마나 동의하십니까?

1) 외부 사설 서비스 이용료가 너무 높다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

2) 사설 서비스가 기술적인 도움이 되지 않는다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

3) 정부관련 R/D기회에 대한 정보가 충분하지 않다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

4) 공공서비스에 관련된 행정절차와 승인절차가 복잡하다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

5) 관련 산업협회(예:석유화학협회 등)와 학회(예: 화학공학회 등)에 대한 정보가 부족하다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

6) 지역 내에 위치한 국가R/D센터에 대한 정보가 부족하다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

7) 외부의 기술적 도움이 적절한 시간 내에 이루어 지고 있지 않다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

8) 외부 기술서비스가 지리적으로 너무 원거리에 위치해 있다

1 (아주 동의하지 않음) 2 3 4 5 6 7 (아주 동의함)

13. 귀사와 자원을 공유(예: 산업공생)하는 타 기업은 어느 곳에 위치하고 있습니까?

1) 같은 지역 2) 다른 지역 3) 해외

14. 자원공유(산업공생)은 귀사의 산업활동에 얼마나 도움이 되고 있습니까?

1 (도움이 되지 않음) 2 3 4 5 6 7 (아주 도움이 됨)

15. 하기에 명시된 요소들은 귀사의 자원공유(산업공생)에 얼마나 중요합니까?

1) 천연자원

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

2) 인프라자원 또는 물질자원

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

3) 산업자원 (기술 또는 경쟁력 등)

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

4) 인적자원 (노동력, 비용, 지식 등)

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

5) 관습적, 제도적 자원 (규정, 루틴 등)

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

16. 하기에 명시된 요소들은 귀사의 자원공유(산업공생)에 얼마나 중요합니까?

1) 정부지원 (재정적 지원, 보조금, 제도적 지원, 규제 등)

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

2) 비용적 동기 (폐기물 처리비용 감소 등)

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

3) 기업윤리 (CSR 또는 사회공헌)

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

4) 기타 (적어주십시오):

1 (중요하지 않음) 2 3 4 5 6 7 (아주 중요)

설문이 종료되었습니다. 설문응답에 참여해 주셔서 대단히 감사드립니다.

Appendix III: Full Names of Variables

Variables	Full Names
Employees	The number of employees
Sales	Annual sales
Invest_Green	Investment in growth growth-oriented technology
Harm_Reduce	Harmful substance reduction
Green_Innov	Green Innovation capability intensification
Purify	Environment purification activity (volunteer service)
Env_Edu	Environment education
Raw_Mat	Purchase of environmental-friendly raw materials
RD_Priv	Private (contract) R&D
RD_Priv	Management support/consulting
Testing	Testing services
RD_Uni	University research
RD_Gov	Government R&D
Gov_Help	Government financial/business assistance
Consortia	Research consortia
Customer	Customer firms
Supplier	Supplier firms
Competitor	Competitors
Networks	Informal business networks
Associate	Industry associations
Conference	Academic converence
Buy_Tech	Purchase of green technology
External	External Factors
RD_Own	Company’s own R&D center
New_Busi	New entry to green-related business
New-Process	New development of green-oriented industrial process

New_Product	New Launch of Green-Oriented Products
New_Tech	New Development of Green Technology
Green_Spinoff	Establishment of an affiliated or spin-off firms based on green technology
Green_Diversify	Diversification of the existing business, processes, technology, or products
Green_Improve	Improvement of the existing business, processes, technology, or products
Fees	Fees for private external services
Services	Private technical services
Info	Information about government-related R&D opportunities
Paperwork	Paperwork and approval to access public services
Lack_Info	Lack of information available about industry association and academic conference
Tech_Help	External technical help
Tech_Distance	Distance of external technical Services
Share_Same	Sharing within same region
Share_Other	Sharing with other region
Share_Abroad	Sharing with abroad
Share_Benefit	Beneficial from resource-sharing
Resource_Share	Natural resources
Infra_Share	Infrastructural and material resources
Tech_Share	Industrial resources (technology and firm competency)
HR_Share	Human resources (labour skills, costs, knowledge)
Rules_Share	Institutional endowments (rules, routines, norms)
Gov_Support	Government support (financial supports, subsidy, institutions, regulations)
Costs	Cost motive (reduction in waste management)
Ethic	Business ethic (CSR or social contribution)

Appendix IV: Questionnaire, Related Literatures, and Related RQs.

<table>
<tr><th>Questionnaire</th><th>Related Literature</th><th>Related RQs</th></tr>
<tr><td>Q1</td><td rowspan="7">General Information</td><td rowspan="7">N/A</td></tr>
<tr><td>Q2</td></tr>
<tr><td>Q3</td></tr>
<tr><td>Q4</td></tr>
<tr><td>Q5</td></tr>
<tr><td>Q6</td></tr>
<tr><td>Q7</td></tr>
<tr><td>Q8</td><td>Lee & Woo (2010)</td><td>RQ1</td></tr>
<tr><td>Q9</td><td>MacPherson (1997)
Gress (2015)
Arndt & Sternberg (2000)</td><td>RQ1</td></tr>
<tr><td>Q10</td><td>Isaksen & Jakobsen (2017)
Grillitsch (2016)
Grillitsch & Asheim (2018)</td><td>RQ1, RQ2(a)</td></tr>
<tr><td>Q11</td><td>Trippl et al. (2019)</td><td>RQ1</td></tr>
<tr><td>Q12</td><td>Arndt & Sternberg (2000)
Gress (2015)</td><td>RQ2(b)</td></tr>
<tr><td>Q13</td><td>Jensen, et al. (2011)
Chertow (2000)</td><td>RQ3</td></tr>
<tr><td>Q14</td><td>Chertow (2007)</td><td>RQ3</td></tr>
<tr><td>Q15</td><td>Trippl et al. (2019)</td><td>RQ3</td></tr>
<tr><td>Q16</td><td>Jones (1980)
Chun & Kim (2011)</td><td>RQ3</td></tr>
</table>

국문초록

진화경제지리학, 산업공생 및 녹색성장지향적 과정

– 울산 · 미포국가산업단지 내에 위치한 석유화학기업에 대한 소규모 연구 –

강민근

사범대학 사회교육과 지리전공

서울대학교 대학원

지구온난화로 비롯된 기후변화와 같은 환경문제가 시간에 지남에 따라 그 정도가 심해지고 있는 상황 속에서 새로운 지속가능성장방식에 대한 수요가 증가하고있다. 이러한 부분에서 녹색성장은 경제성장과 환경지속성을 동시에 추구할 수 있다는 점에서 주목을 받고 있다.

본 연구는 대한민국에서 행해지는 녹색성장과 산업공생을 진화경제지리학의 시각으로 탐구한다. 경로의존, 경로창출, 경로다각화와 제도 및 정치적 부분과 같은 진화경제지리학의 핵심개념을 통하여 울산 · 미포국가산업단지 내에 위치한 석유화학기업의 녹색진화과정을 연구한다. 특히 녹색성장전략의 중심인 산업공생을 집중적으로 살펴본다.

진화경제지리학, 산업공생, 그리고 석유화학산업에 관한 기존 문헌들을 검토한 뒤, 울산 · 미포국가산업단지의 경로발전의 다중행위자 및 다중공간적 진화과정을 연구하고 산업공생을 진화경제적 시각으로 바라보기 위하여 본 연구는 세 가지 연구질문을 설정하였다.

본 연구에 필요한 데이터는 2020년 10월 27일부터 2020년 11월 16일까지 전자설문지를 통하여 취득하였으며 본 설문지는 환경기술자 및 관련

부서 관리자에 의해 작성되었다. 본 연구는 기술통계, Mann−Whitney U 검정, 그리고 Kendall’s Tau B 검정과 같은 양적방법론을 사용하였으며 데이터 신뢰도는 Chronbach’s Alpha를 통해 확보하였다.

본 연구는 울산·미포국가산업단지에서 녹색진화과정이 일어나고 있음을 다차원으로 확인하였다. 첫째로, 석유화학기업들은 외부네트워크로부터 공급된 새로운 지식을 통하여 신경로를 창출하였다. 둘째, 신지식은 기업들의 기존자원과 결합하여 경로다각화를 유발한다. 석유화학산업의 오래된 업력으로 인하여 울산·미포국가산업단지 내의 석유화학기업들은 기존의 산업시스템에 의존하는 기술적 고착효과를 겪고 있다. 진화경제지리학에서 주장하는 바와는 다르게 녹색성장과 관련한 파생효과는 나타나지 않았다.

경로발전의 진화에 덧붙여, 본 연구는 울산·미포국가산업단지내에서 산업공생의 형성을 확인하였으며 이는 연구기관과 같이 지식을 창출하는 행위자들과의 네트워크에 기인한다. 정부지원 또한 녹색성장에 기여하는 바가 있으나, 비효율적인 행정서비스는 기업의 녹색활동을 저해하는 요인으로 드러났다. 문화적 규정과 같은 제도적 부존점은 기업에게 있어 녹색성장지향적 그리고 산업공생적 관계와 행위에 있어 중요한 요인으로 밝혀졌다.

본 연구는 다음과 같이 두 가지 부분에서 학문적 공백을 메우고자 한다. 첫째로, 기존의 진화경제지리학에서는 경로발전의 주체가 모호하다는 비판이 있었으나 본 연구에서는 경로발전에 주체는 기업임을 확인하였다. 예를 들어 기업 간 산업공생의 관계는 기업중심이며 지역과 지역의 연결을 촉진하는 행위자는 국가로 밝혀졌다. 둘째로, 녹색성장에 관해 정치적 담론이 주를 이루었던 기존의 연구경향에 새로운 통찰을 제시할 수 있다. 녹색성장을 녹색혁신역량, 환경정화, 환경교육, 그리고 친환경 자재구매와 같은 기업의 역할을 지리적 시각으로 분석함으로써 기존연구에서 찾아볼 수 없는 새로운 학문적 시야를 확보하는데 일조하였다.

주요어: 진화경제지리학, 녹색성장, 산업공생, 경로창출, 경로의존, 경로다각화

학번: 2018−28863