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Research Article

Analysis Of Competitiveness In The Domestic Semiconductor Cluster Using Entropy Technique: Based On The GEM-ESG Model

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ARTICLE INFO **ABSTRACT**

Purpose – The study aims to conduct an empirical analysis of semiconductor cluster integrated competitiveness with a focus on the GEM-ESG model. Specifically, the study seeks to compare and analyze the development factors of semiconductor clusters in different regions. The results of the empirical study will reveal a clear concentration phenomenon in the semiconductor industry clusters of some regions.

Design/Methodology/Approach – Previous research has established the factors influencing the competitive advantage of industrial clusters. The study collected competitive indicators from major South Korean cities and regions, incorporating these into the GEM model, and exploring ESG indicators relevant to the semiconductor industry. The study utilized Entropy Technique analysis to empirically assess the competitiveness of the South Korean semiconductor cluster and conduct comparative testing of the research findings.

Findings – The results revealed a concentration phenomenon in the semiconductor industry clusters of Yongin and Chungbuk Province. Additionally, the study highlighted the importance of factors such as "groundings (G)", "enterprise management (E)", "market conditions (M)", and ESG practices in determining competitiveness.

Research Implications – Through empirical analyses, the study emphasizes the significance of GEM and ESG factors in the analysis of industrial clusters, particularly in contributing to long-term sustainability and competitive advantage focusing on the collaboration and alignment of ESG values.

Keywords: cluster, competitiveness, entropy technique, ESG management, GEM-ESG, semiconductor

JEL Classifications: L16, M21, O12

INTRODUCTION

Global competition following the COVID-19 pandemic is influenced by various factors such as digitalization, localization, ESG management, supply chain stability, and technological innovation (Bauer et al., 2020; Lee et al., 2021; Lee et al., 2023). Events like COVID-19 and the US-China trade war have disrupted supply chains, particularly in the global semiconductor sector (Stephens, 2022).

In response, governments and companies are implementing strategies such as new cluster collaboration systems (Lee & Lee, 2016; Chen, 2023) to improve supply chain stability. For example, the US has allocated $25 billion through the "Endless Frontier Act" to support the semiconductor industry, demonstrating the government's commitment to cluster development. This investment is crucial for sustainable development and global competitiveness. In Austin, Texas, "SEMATECH" is promoting semiconductor development through collaboration, highlighting clusters as innovation hubs. Japan and Germany are also investing in semiconductor clusters to address supply chain crises, with Japan designating the semiconductor industry a key sector, and providing substantial support.

Korea is addressing global supply chain stability through measures such as regional production dispersion, supplier diversification, and quality management (Lee Jun, 2022). In the semiconductor industry, which is vital to Korea's economy, leading companies are strategically incorporating ESG considerations (Lee Hyeong

Gyu, 2022; Kim, 2022), focusing on waste disposal, energy efficiency, and greenhouse gas emissions mitigation. Socially, they prioritize job creation, community collaboration, and sustainable growth. Corporate Social Responsibility (CSR) covers industrial accidents, human resources, labor relations, and supply chain management. Transparent practices within clusters are essential for growth, and compliance with ESG indicators enhances company sustainability and social trust (Hoang et al., 2020; Porter & Kramer, 2014; Sung, 2014). Korea's strategic initiatives emphasize adaptability, collaboration, and a comprehensive ESG framework for resilient economic development.

While recognizing the significance of semiconductor cluster development and the increasing focus on ESG factors, there is a need for empirical research to investigate the impact on competitiveness, innovation, and sustainability, including operational mechanisms.

This research aims to establish a framework for the sustainable advancement of semiconductor clusters integrating ESG management, drawing from recent environmental changes and established theories. Investigating industrial cluster concentration enhances competitiveness, with positive effects on regional economic growth and national competitiveness. The amalgamation of ESG management with innovative technologies requires reconfiguring "business models and cluster models" for the sustainable progression of semiconductor clusters, fostering innovation and fortifying sustainable competitiveness.

LITERATURE REVIEW

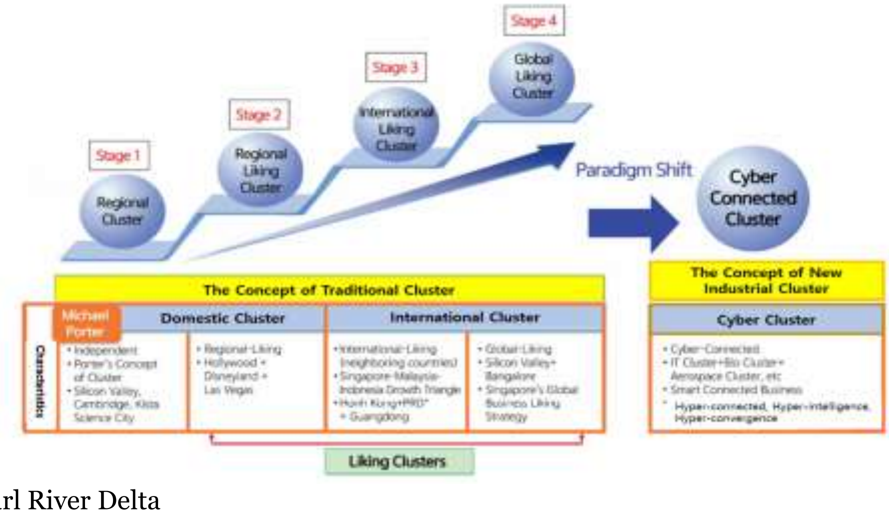
1. Cluster Theory and Research Trends in Domestic Semiconductor Industry Clusters

The theory of industrial clusters, initially proposed by Marshall (1980), and further elaborated upon by Porter (1990, 1998), elucidates economic cooperation among geographically proximate firms to enhance competitiveness and foster growth.

It advocates vertical collaboration for efficient production, and horizontal collaboration for market exploration, playing a crucial role in economic advancement and innovation.

Expanding on this concept, our research focuses on the development of clusters, specifically examining "internationally linked clusters", as discussed by Moon and Jung in 2008. These clusters transcend national boundaries, contributing to sustained competitive advantage. With the advent of Fourth Industrial Revolution technologies, clusters have evolved into cyber-connected entities that transcend the traditional constraints of time and space (see Fig. 1).

Figure 1. Evolution of Clusters



Note: *PRD: Pearl River Delta
Sources: Jung Jin-Sup (2023), Jung Jin--Sup and Lee Min-Jae (2018) and Moon Hwy-Chang and Jung Jin-Sup (2008).

A review of literature on the sustainable development of clusters indicates a consensus regarding the need for continual changes and advancements to improve competitiveness. Scholars have investigated transition strategies for clusters, with a focus on implementing sustainable development approaches (Choe, 2021; Jung et al., 2017; Jung & Woo, 2021; Kim, 2012; McKernan & McDermott, 2022; Moon & Jung, 2008; Park et al., 2020; Park & Lee, 2022).

Moon and Jung (2008) conducted a case study on prominent clusters, such as Silicon Valley and Sista, deriving novel concepts and strategies for cluster development. Jung and Lee (2018) underscored the significance of new driving forces, including cyber-connected clusters, for sustainable development in traditional manufacturing industries. Li et al. (2022) explored the relationship between maritime industry clusters and port city redevelopment, emphasizing the importance of port city regeneration for maritime industry cluster activation.

In the context of the competitive position of the domestic semiconductor industry, early 20th century historical research focused on development and status, later shifting to output competitiveness and value/supply chain analysis influenced by global dynamics (Kim, 1989). Modern research adopts an empirical approach, utilizing indicators for analysis. Jang (2006) employed MS, EBI, and IE indices to identify strategies to enhance the industry, while Kim and Seo (2021) assessed competitiveness using the MS, TSI, RCA, and ESI indices. Quantitative methods have also been utilized to analyze technological competitiveness.
In the early 21st century, amidst global challenges, research on domestic semiconductors has shifted focus to ESG, data transformation, and industrial clusters. ESG has become a crucial guideline for companies, enhancing semiconductor enterprise value and ensuring sustainable operations (Jeong & Kim, 2023).

2. ESG Management in Clusters

The significant industrialization of Western nations since the 1960s has resulted in various environmental challenges compared to the environmental conditions of that era. As industrialization advanced, human activities negatively impacted the environment, as evidenced by Rachel's "Silent Spring (1962)", which highlights the complex relationship between economic growth, global population shifts, consumer behavior, and limited environmental resources. Scholars like Maler (1974) have suggested regulations to decrease greenhouse gas emissions, while O'Riordan (1981) advocated for the practical implementation of environmentalism beyond theoretical discourse. Stahel's (1986) approach laid the groundwork for "industrial ecology", concentrating on prolonging product lifespan and establishing circular systems within industries. Conversely, Frosch and Gallopoulos (1989) introduced the concept of a "circular system of industries", wherein waste serves as raw materials for new processes, reducing waste and mitigating environmental risks within clusters. These concepts contributed to the evolution of industrial ecology. In 2011, the United Nations Industrial Development Organization (UNIDO) introduced ESG as part of the sustainable development framework. Woźniak (2022) examined the case of the Polish industrial cluster ecosystem from a business and corporate-based strategy perspective, supporting ESG practices. Liu and Stephens (2019) and Lopez et al. (2022) investigated the influence of corporate social responsibility (CSR) strategies on management and governance axes for sustainable growth. ESG, sustainable development, and the circular economy are interconnected within industrial cluster ecosystems. ESG factors are essential to responsible social and environmental operations within industrial clusters (Babkin et al., 2023). Active involvement in ESG activities and collaboration among companies within a cluster enhance overall sustainability and competitiveness. Industrial clusters promote competition and cooperation, facilitating the sharing and interaction of ESG activities. Industrial clusters also play a crucial role in relationships with local communities. Collaboration between cluster companies and local communities fosters regional development and social value creation, contributing to sustainable regional development (Kao, 2023). Governments are encouraged to integrate sustainable management (ESG management) into the strategies of industrial clusters, as emphasized by Kao (2023). Progressive company efforts to implement sustainable development indicators, including ESG, within clusters promote sustainable environmental development across the industry. Bhattacharya and Bhattacharya (2023) examined key factors influencing the business model of the biopharmaceutical industry and proposed ways in which ESG management could drive business model innovation. Ali (2023) identified ESG as a quantitative predictive variable for the life cycle stages of industrial clusters, proposing frameworks that apply ESG indices. These frameworks, such as the one proposed by Ali (2023), enable companies to enhance supply chain sustainability through cluster participation.

3. ESG Management

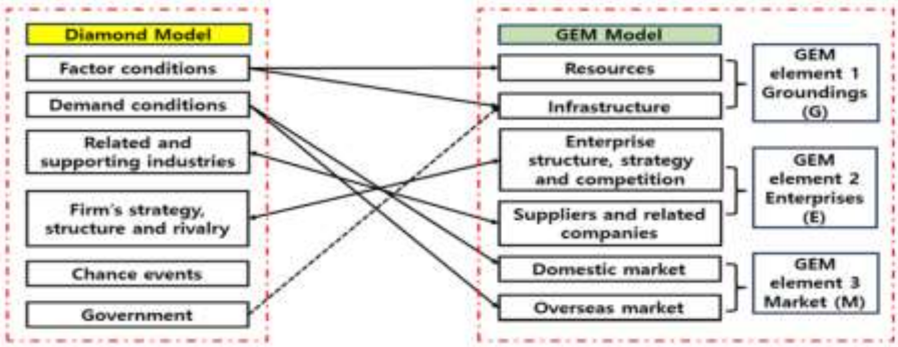
The ESG (Environmental, Social, Governance) strategy refers to a business approach in which companies take into account environmental, social, and governance issues in operations. The concept of ESG emerged in the late 20th century, and gained momentum through international initiatives such as the "Earth Declaration" and the "Action Plan for Sustainable Development" in 1992. The universalization of ESG gained prominence in the early 21st century, with the United Nations Environment Program (UNEP) and the European Investment Bank (EIB) issuing ESG-focused investment guidelines in 2006. The COVID-19 pandemic in 2020 further emphasized the importance of sustainable development for economic growth, thereby amplifying the significance of ESG (Boffo & Patalano, 2020).
ESG management has become essential for corporate survival and prosperity, leading companies to adopt ESG practices. Research on ESG typically focuses on evaluating a company's ESG issues and analyzing the impact on the company's value. Methodologies for ESG evaluation encompass social, environmental, and governance responsibilities. In the context of domestic companies aiming to establish an "innovation ecosystem" for global growth, Zhen et al. (2023) emphasized the critical moderating role of ESG management in the relationship between electric vehicle attributes and purchase intent, showcasing the diverse applications of ESG in shaping consumer behavior.
In the realm of cluster-related policies, governments active promote an innovation ecosystem by creating institutional infrastructure, supporting supply chain inspections, facilitating international trade negotiations, enhancing internal and external communication for ESG improvement, and aiding the ESG activities of small and medium-sized enterprises (SMEs). The government also aligns SME growth with social values, expanding models for sustainable growth (Clément et al., 2023). Strategies that integrate ESG management

and clusters involve enhancing industrial complexes through ESG, digitalization, greenification, and tailored support, as exemplified by initiatives like the Gumi Industrial Complex and Pangyo Techno Valley.
Achieving harmonious development between an industry and the environment requires integrating ESG with cluster development. To enhance cluster competitiveness, it is crucial to have both a “vertical understanding” of development levels and trends, and a “horizontal understanding” of cluster strengths and weaknesses. This study aims to analyze the current ESG status of clusters by incorporating ESG into the evaluation of cluster competitiveness, and conducting empirical analyses based on this integration.

4. GEM Model vs. Diamond Model

The GEM model is composed of three essential components: Groundings (G), Enterprises (E), and Markets (M), which collectively impact the competitiveness of regional clusters. Groundings encompass the vital resources and infrastructure necessary for production, playing a fundamental role in national competitiveness by fostering innovation and competition. Enterprises encompass a company’s strategy, structure, competition, and related industries, influencing its competitiveness through efficient resource allocation, capabilities, and collaboration. Markets refer to the domestic and international markets wherein companies operate, with the domestic market providing a foundation for growth, and international markets offering new opportunities.
Derived from the diamond model, the GEM model emphasizes the interconnectedness of its elements and the role of local governments in cluster development. Scholars have expanded and enhanced the GEM model, introducing variations that consider additional factors. For instance, the GEM-S model by) includes technological factors, analyzing regional technological innovation capabilities. The GEM-N model by Liu and Liu (2010) and Songquan and Minrong (2017) integrates innovation capability factors into the GEM model, focusing on regional innovation capabilities. Zhang et al. (2017) proposed the GEM-Pearson-VC model, adding methodological aspects for adversarial analysis, enhancing accuracy and flexibility. Mao-Xiaoli & Yang-Shihua (2021) introduced the G2 EM-CI model, incorporating government and value chain factors, emphasizing their roles in competition.
These modified models enrich the GEM model by considering a broader range of factors in the analysis of regional competitiveness. The diversity of studies contributes to the formulation of comprehensive policies and strategies for regional development.

Figure 2. Comparison of the Diamond Model and GEM Model



Note: In the diamond model, external factors are considered, while in the GEM model, internal factors such as infrastructure development are considered and represented by dotted lines. Additionally, the arrows representing the relationship between related and supporting industries, as well as the strategies, structure, and competition of enterprises, remain the same in both models. However, chance events are excluded from the GEM model.

Source: Yang and Yang (2003)

RESEARCH DESIGN

Enhancing Cluster Performance through the Innovation of Groundings (G)

In the context of resource-efficient cluster development, technological innovation stands out as a pivotal factor in enhancing competitiveness. Firms within a cluster can rapidly innovate through knowledge sharing and collaboration, playing a crucial role in accelerating technological advancements. This innovation serves the dual purposes of improving production efficiency and utilizing clean energy sources for environmental protection. Higher education and technology are indispensable in achieving these goals, with the aim of producing specialized researchers for technological research being a key objective of higher education.
Simultaneously, the research findings of Cheng (2022) highlight the significant impacts arising from the fusion development of “finance + technology” on credit loans and risk levels. Integrating Miao Cheng’s insights emphasizes the diverse influences on cluster dynamics. Technological research, whether conducted

by specialized departments, individuals, or institutions, enhances production technology, resource utilization, and the discovery of new energy sources. Resource efficient manufacturing clusters, driven by R&D capabilities, technological innovation, and open innovation, not only cut production costs and boost economic benefits but also optimize specialization and improve industrial status within the production chain (Shin & Lim, 2014; Yoon & Choi, 2008).

The establishment of industrial clusters positively impacts venture companies, as indicated by Seo et al. (2012), who found collaborative networks, R&D professionals, intellectual property rights, and technological excellence to be influential factors. Entrepreneurial spirit, highlighted by Jang and Park (2010), has positive effects on technological competitiveness, excellence, innovative product sales, and innovation activities. Factors influencing the formation of clusters in the Seoul area, such as transportation convenience, play a significant role (Jang & Park, 2010). In studies on the Incheon bio-industry cluster, transportation and logistics convenience, bio-industry integration, and suitable business locations significantly impact overall site satisfaction.

Aging production facilities within a cluster can detrimentally affect productivity and efficiency, leading to decreased competitiveness. Preventing aging and promoting modernization are crucial to maintain and improve competitiveness. Collaborative efforts, including information sharing on modernization and maintenance, as well as collaborative research and development, contribute to sustaining and naturally developing the overall competitiveness and growth of the cluster (Cho, 2005).

H1: The innovation of Groundings (G) can enhance cluster performance.

Promoting Cluster Performance through the Innovation of Enterprises (E)

Corporate innovation, which refers to a company's capacity to generate original concepts, products, services, and procedures to gain a competitive advantage and foster growth, is closely associated with cluster performance. Clusters, which are geographic concentrations of similar industries, promote competitiveness and innovation through collaborative efforts and the exchange of knowledge among companies (Moon & Jung, 2008; Porter, 1990; Burns et al., 1994; Hull and Hage, 1982). The established relationship between corporate innovation and cluster performance has been well-documented (Jeong et al., 2016). Within clusters, companies achieve innovation through collaborative endeavors, such as joint research and development with rival firms, or by leveraging technology and knowledge sharing to create new products and services. Clusters function as centers for specific technologies, knowledge, and human resources within an industry, thereby facilitating easier access to new innovations (Lee et al., 2011). Moreover, companies that innovate within clusters tend to surpass competitors, gaining a competitive edge and expanding market share. The efficient utilization of human and material resources through technology and knowledge sharing in clusters leads to cost savings and economic advantages (Choi & Kim, 2016). As a result, achieving innovation within clusters is a critical factor in enhancing the competitiveness and growth of companies and industries. Companies that develop innovative products or services and actively participate in cluster collaborations contribute not only to the success of the cluster itself but also to the overall growth and economic benefits of the entire industry.

H2: The innovation of Enterprises (E) can promote cluster performance.

Increasing Cluster Performance through the Expansion of the Market (M)

Jang, Baek, and Jung's (2016) research emphasized the significant influence of company capabilities and the domestic market environment on the management performance of agricultural food processing firms. The study also highlighted the impact of cluster performance on the overall performance of these companies. Market performance, which includes metrics such as sales, exports, revenue, and market share, is essential for competing effectively in the market (Lee et al., 1998; Kwon, 1996; Park & Lee, 2010). Conversely, cluster performance is assessed through collaborative factors such as cooperation among competing companies, joint research, and knowledge sharing within a specific region or industry group (Eun, 2015; Kwon & Lee, 2005; Park & Yoo, 2007). The market performance and cluster performance of firms are mutually influential and interactive. Collaborative activities within clusters promote improved relationships among competing companies, thereby enhancing competitiveness in the market and contributing to the development of superior products or services (Yoon & Choi, 2008). Furthermore, cluster collaboration enables companies to secure more resources and manpower, leading to increased economic benefits for individual companies, and higher productivity for the entire industry group (Lim et al., 2006; Nam & Lee, 2013). Consequently, within an industry group, cluster performance positively affects market performance. Companies engaged in cluster collaboration, maintaining collaborative relationships within clusters, often achieve higher performance compared to competitors. Active cluster collaboration not only benefits the growth of individual companies but also contributes to the overall development of the industry group, and positively impacts regional economic growth (Kim Hong-Bae et al., 2015; Park & Lee, 2010).

H3: The expansion of the Market (M) can increase cluster performance.

In the previous theoretical discussion, a review of prior research on industrial cluster competitiveness was conducted. Previous studies on cluster competitiveness did not include the importance of ESG concepts in the evaluation system. Therefore, in this study, we constructed a GEM-ESG model by adding important indicators of ESG, which represent sustainable development, to the basic GEM model. After constructing the

GEM-ESG model, we aim to comprehensively evaluate the competitiveness scores of semiconductor industry clusters in each city (or region) based on the weights determined using the entropy method. The research model follows.

Increasing Cluster Performance through ESG Management Strategies

Based on the findings of Lee et al. (2023), the integration of ESG strategies in Chungcheongbuk-do is anticipated to yield favorable outcomes for the advancement of the bio-industry cluster. Furthermore, Wu et al. (2023) demonstrated the significant influence of a company's ESG strategy on industrial carbon emissions. Previous studies have also examined the effects of ESG on the sustainability and effectiveness of supply chains, particularly within intricate industrial clusters characterized by multifaceted supply networks involving numerous firms. In the context of financial implications, Kwon and Shin (2022) and Zhu (2022) contributed insights by highlighting that ESG management can enhance corporate (stock price) value, showing a significant positive correlation. This underscores the broader impact of ESG strategies on the financial performance of companies, providing a comprehensive perspective on value proposition. Consequently, the following hypothesis is proposed based on the existing body of research.

H4: ESG management strategies can increase cluster performance.

5. Enhancing the Performance of Clusters by Concentrating Industrial Activities within the Cluster

A study conducted by Liu and Wang (2022) demonstrated that the utilization of agricultural industry clusters can effectively improve the competitiveness of environmentally friendly agricultural product brands. Additionally, research conducted by Marco-Lajara et al. (2022) indicated that the competitive edge of innovative cocktail development is associated with industrial clusters and collaborative efforts.

H5: Industrial cluster concentration can increase cluster performance.

This article investigates the semiconductor industry cluster effect in various regions of Korea by examining GEM theory, ESG research, and industrial cluster theory.

The study employs a research model, depicted in Fig. 3, to analyze the impact of GEM·ESG·R on the semiconductor cluster. The entropy method, a multi-index comprehensive evaluation, is utilized to objectively determine weights for indicators, reflecting relative importance. Key functions of the entropy technique include enabling multi-index comprehensive evaluation, facilitating scientific weight allocation, supporting differential analysis, ensuring data standardization, and providing decision support.

In summary, the entropy technique serves as a robust tool to scientifically evaluate and compare the competitiveness of the semiconductor industry across regions, offering valuable assistance to decision-makers.

Figure 3. Research Model.

$$S_i = \sum_{j=1}^{m} \omega_j r_{ij} = GEM \cdot ESG \cdot r_a$$

In this context, the variable "S_i" represents the final score, "w_j" denotes the weight determined by the entropy method, "r_{ij}" represents the index value, "i" refers to the sample city (or region), and "j" represents a dimensionless value. Furthermore, considering the issue of industrial concentration that affects the influence of industrial clusters, this study added the value of r (EG coefficient). In the process of calculating concentration (industrial concentration), it is not necessarily the region with the highest industrial concentration that has the highest industrial agglomeration, as the value of location entropy (LQ analysis) does not reflect the difference in regional economic development levels. The Herfindahl index (G_a), a measure of spatial concentration, also has the same drawback as location entropy (LQ analysis). In other words, the Herfindahl index (spatial Gini coefficient) does not accurately reflect the spatial concentration of industries, as it ignores differences in regional areas. Therefore, in this study, we selected the "modified EG coefficient", and its formula follows.

$$r_a = \frac{\dfrac{G_a}{1-\sum X_i^2} - \dfrac{1}{n}}{1-\dfrac{1}{n}} \tag{9}$$

In the case where G_a is the spatial autocorrelation coefficient, the equation is as follows. , In the case where a is the spatial autocorrelation coefficient, the equation is as follows. X_i represents the ratio of the specific industry size in region i to the overall size of the industry. S_i represents the ratio of the overall industry size in region i to all industries. n is the number of firms in the respective industry within the region. The original GEM model consists of three elements: Groundings (G), Enterprises (E), and Market (M). The GEM-ESG model, developed in this study, is a newly created model that incorporates ESG indicators into the basic GEM model.

IV. Definition of Variables

Table 1 presents the variables of the research model. The first dimension consists of the GEM model and the ESG model. The Groundings (G) of the GEM model includes detailed items such as the number of semiconductor cluster researchers, production facilities for advanced ceramics by region, human resources in the advanced ceramics industry, national research and development project expenditures, government R&D investment, and transportation culture index. Enterprises (E) include variables such as the business innovation

Inno-Biz index, the number of businesses in the advanced ceramics industry, research and development expenses in the advanced ceramics industry, and management innovation index. Market (M) includes variables, such as the proportion of advanced ceramics sales to total company sales, per capita GDP by city (or region), sales of the advanced ceramics industry, and total sales of semiconductors.

In the ESG model, the Environment (E) includes variables such as energy consumption (e.g., fuel, electricity) and air pollution levels, while Social (S) includes variables such as the population engaged in volunteer activities, employment rate of people with disabilities, and social welfare investment. Governance (G) includes variables such as the ratio of male to female executives and the proportion of external directors in companies. This study aims to evaluate the development level (competitiveness) of semiconductor clusters in each region based on these indicators.

Table 1. Definitions of Variables in the Research Model

One Dimensional Metrics		Two Dimensional Metrics	Three Dimensional Metrics
GEM Model	Groundings (G)	Number of researchers in the semiconductor cluster	G1
		Production facilities for advanced ceramic industries by region	G2
		Workforce in the advanced ceramic industry	G3
		Amount of national research and development projects	G4
		Government investment in research and development	G5
		Transportation culture index	G6
	Enterprises (E)	Business innovation Inno-Biz index	E1
		Number of companies in the advanced ceramic industry	E2
		Research and development expenses in the advanced ceramic industry by companies	E3
		Management innovation index	E4
	Market (M)	Proportion of advanced ceramic industry sales to total company sales	M1
		GDP per capita by city (or region)	M2
		Sales revenue of the advanced ceramic industry	M3
		Total sales revenue of the semiconductor industry	M4
ESG Management	Environment (E)	Energy consumption (e.g., fuel, electricity)	E'1
		Air pollution level	E'2
	Society (S)	Number of volunteers engaged in community service	S1
		Employment rate of people with disabilities	S2
		Amount of social welfare investment	S3
	Governance (G)	Proportion of male and female executives	G'1
		Proportion of external directors in companies	G'2

1. Sample Characteristics

The purpose of this study is to compare the competitiveness of major semiconductor clusters in South Korea, and to provide implications to enhance the competitiveness of semiconductor clusters. To achieve this research objective, it is important to select representative urban samples that can accurately compare the differences and similarities of various city (or region) semiconductor clusters. By correctly comparing multiple cities, valuable conclusions and implications can be derived.

Appropriate sampling methods and target selection are crucial in increasing reliability in data collection. Maintaining accuracy in the data collection process is also necessary. In this study, various statistical and government agency websites were utilized to enhance the accuracy and reliability of the data. Government agency data is generally reliable as it is managed in an official and trustworthy manner, adhering to standardized procedures and regulations for data collection and management, ensuring data consistency.

In this study, a competitiveness evaluation model incorporating ESG capabilities for sustainable development was constructed to measure the competitiveness of semiconductor clusters. Before analyzing the competitiveness of semiconductor clusters, cities or regions with a certain scale of semiconductor clusters were selected as sample cities. The selection criteria were based on the high level of "total value added of the semiconductor industry" and the high "export value of semiconductors" in the local area. The semiconductor industry in Korea is mainly concentrated in the central and metropolitan areas, with the Chungcheongnam-do, Chungcheongbuk-do, and Gyeonggi provinces as the most prominent. Additionally, the development of clusters in Gangwon-do province and Incheon city, where new semiconductor companies are entering, is emphasized. Therefore, these four locations (two cities and two regions), Chungnam province, Chungbuk province, Gyeonggi (Youngin city), and Incheon city, were selected as sample cities and regions for this study.

2. Hypothesis Testing

After data collection, the entropy method and geographic space analysis (using GeoDa) were used. The entropy method is an analytical approach used to evaluate the relative values of alternatives in multi-criteria decision-making problems. It measures how well alternatives satisfy each criterion, and calculates the relative values. It is commonly used for alternative selection and weight assignment in multi-criteria decision-making problems.

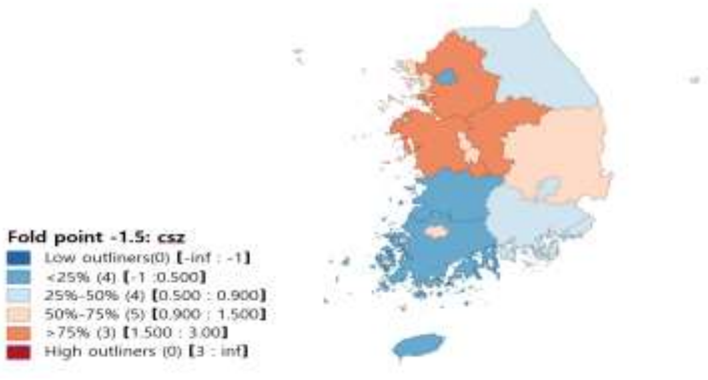
GeoDa is a specialized statistical software for spatial analysis that allows for the analysis of Moran's I. Moran's I is a statistical indicator that measures the spatial autocorrelation of spatial data, indicating the spatial self-correlation of spatial data. This index can be used to identify spatial patterns and determine if there is spatial autocorrelation. In other words, through the analyses of Moran's I index, the spatial autocorrelation, spatial concentration dispersion, and local interactions of the semiconductor industry can be examined. Moran's I value ranges from -1 to 1, wherein positive values indicate positive correlation representing spatial autocorrelation, and negative values indicate negative correlation. Significance test results are also examined to determine if the spatial autocorrelation is statistically significant.

RESEARCH FINDINGS

3.1. Regional Coefficients and Lisa Analysis in Advanced Industries

The Lisa analysis in Fig. 4 reveals that the semiconductor industry in Korea is primarily concentrated in Seoul, Incheon, Gyeonggi, Chungbuk, and Chungnam. This geographical concentration gives rise to large-scale clusters radiating into the surrounding areas, which aligns with the characteristics of industrial clusters. In these areas, the presence of cluster phenomena was indicated by Lisa values greater than 0.5, but less than 1. When Moran's I is greater than 0, it signifies a positive spatial correlation in the data, with higher values indicating a stronger spatial correlation. Conversely, when Moran's I is less than 0, it indicates a negative spatial correlation (Anselin, 1995).

Figure 4. An Analysis of the Distribution of Lisa in Advanced Industries

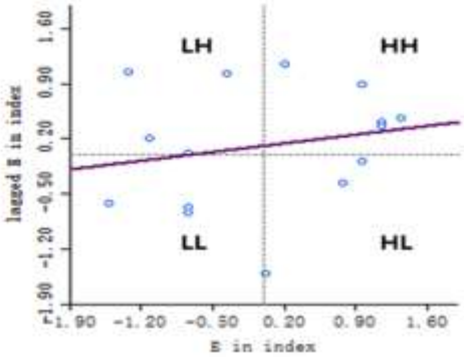


These findings indicate the validation of the process in which industrial clusters evolve from being "regional clusters" to "interconnected clusters" formed between regions, as demonstrated in the step-by-step cluster study conducted by Moon and Jung (2008). This also confirms the fact that the majority of domestic semiconductor companies are concentrated in the central area of Seoul. According to the survey, domestic semiconductor production is concentrated in the metropolitan area (production market share in 2021, 80.7%). This is due to the fact that the main companies, Samsung Electronics (Hwaseong, Pyeongtaek, Giheung) and SK Hynix (Icheon), have their main production facilities located in Gyeonggi Province, and when combined with the adjacent Chungcheong Province (=Chungcheongbuk-do + Chungcheongnam-do) (production market share, 15.8%), these two regions account for 96.5% of domestic semiconductor production.

3.2. Moran's I Analysis

The horizontal axis of Fig. 5 represents the standardized values (z-scores) of the variable for a given unit, while the vertical axis represents the average values (z-scores) of the variable for neighboring units. In other words, it represents the standardized values. Fig. 5 can be divided into four parts: LH, HH, LL, and HL, based on the horizontal and vertical axes. The HH region includes Daejeon, Sejong, Chungnam, Chungbuk, and Gyeonggi, while the LH region includes Gangwon, Seoul, Jeonbuk, and Daegu. Further, the HL region includes Incheon, Gyeongnam, and Gwangju, while the LL region includes Jeonnam, Gyeongnam, Jeonbuk, and Busan.

Figure 5. The Moran's I Analysis for the Semiconductor Industry (0.56 < Moran's I < 1)



Note: The HH region encompasses the areas of Daejeon, Sejong, Chungcheongnam-do, Chungcheongbuk-do, and Gyeonggi-do. The LH region includes Gangwon-do, Seoul, Gyeongsangnam-do, and Daegu. The HL region comprises Incheon, Gyeongsangbuk-do, and Gwangju, the LL region encompasses Jeollabuk-do, Jeollanam-do, and Busan.

When combining Fig. 4 with Fig. 5, it can be observed that the semiconductor industry, as a traditional manufacturing sector, exhibits a clear trend of concentration in regions such as Daejeon, Sejong, Chungnam, Chungbuk, and Gyeonggi. Among these regions, semiconductor companies in Gyeonggi, Chungbuk, and Chungnam account for approximately 80.7% of the national semiconductor industry, and employ around 800,000 people, making it the most prominent semiconductor cluster in Korea. The scale and concentration of the Korean semiconductor cluster make it a representative cluster. Therefore, this study aims to analyze the competitiveness of the cluster by integrating the concept of sustainable development.

EMPIRICAL ANALYSIS

Comparison of Industrial Concentration in Each Regional Cluster

To address the distortion issue of the spatial Gini coefficient, which measures the geographical concentration of industries, Ellison and Glazer proposed a new concentration index based on the concept of the Herdahl index in 1997. The spatial Gini coefficient does not necessarily indicate industrial concentration or clustering as it does not consider differences in company size. For example, the Gini coefficient of a region may increase if there are large-scale companies present, but there may not be a distinct concentration or cluster. However, the EG index, constructed with the help of the Herfindahl coefficient, can overcome this limitation when comparing the concentration of industries.

From Table 2, the following research findings can be derived. When examining the results for the right spatial coefficient, it can be observed that each value is greater than 0 in sequential order. Youngin city (Gyeonggi Province) ranked first, followed by Incheon city, Chungbuk Province, and Chungnam Province. Through data analysis, it is evident that there are significant differences in the size of company in each city or region. However, solely relying on the G (spatial) coefficient cannot accurately determine the concentration of industrial clusters (Ellison & Glaeser, 1999). Therefore, in order to address the limitations of the G coefficient, this paper also considers the analysis of the EG coefficient in relation to company size.

Table 2. A Comparison of G and EG Coefficients across Different Cities and Regions

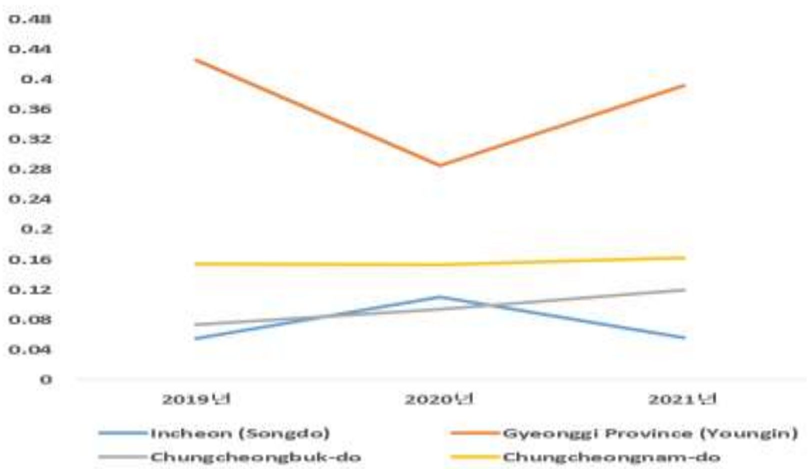
Regional		Si			G (Spatial) Coefficient	EG Coefficient
		2019	2020	2021		
By city	Incheon (Songdo)	-0.0002	-0.00056	-0.0002	0.01396	-0.005
	Yongin (Gyeonggi)	0.00638	0.00379	0.00569	0.01600	0.015
By region	Chungbuk	0.00059	0.00074	0.00112	0.01388	0.012
	Chungnam	0.00045	0.00037	0.00043	0.00400	0.003

In Table 2, the analysis of the EG coefficient on the far right indicates that when the EG coefficient is less than 0.02, it signifies a significant dispersion of industrial distribution within the land area. When the EG coefficient is in the section of 0.02<r<0.05, the spatial distribution of the industry is judged to be relatively uniform. In addition, when the EG coefficient is r>0.05, the industrial space is relatively concentrated; in this case, the industrial concentration or integration is judged to be high (Ellison & Glaeser, 1999). In examining the EG coefficients in this study, the values for Yongin (Gyeonggi Province) and Chungbuk are 0.015 and 0.012, respectively. Due to the limitation of the sample data, these values can be considered close to 0.02. Based on this data, it can be inferred that the concentrations of the semiconductor industry in Yongin (Gyeonggi Province) and Chungbuk are relatively even, while the semiconductor industries in other regions are relatively dispersed. Looking at cities, the reason why the concentration of the semiconductor industry in Yongin (Gyeonggi Province) (0.015) is higher than in Incheon (-0.005) is that Yongin (Gyeonggi Province) has been the economic center of Korea for a long time, and has laid a foundation for the semiconductor industry since its early stages. The electronics industry developed in Yongin (Gyeonggi Province) since the 1970s, which has served as a basis for the semiconductor industry. Additionally, Gyeonggi Province is home to various companies in the semiconductor and related industries, maintaining close relationships with technology and partner companies for production and research and development. Gyeonggi Province is also known for its concentration of world-renowned universities and research institutions, making it easy to secure manpower related to the semiconductor industry. The government also strategically emphasizes the semiconductor industry, promoting research and development and investment, contributing to enhancing the competitiveness of Gyeonggi Province. Furthermore, Gyeonggi Province is a region with developed transportation and infrastructure facilities, providing favorable conditions for logistics and manufacturing. Looking at regions, the concentration of the semiconductor industry in Chungbuk (0.012) is higher than in Chungnam (0.003). Although Chungnam is stronger than Chungbuk in terms of semiconductor R&D and innovation, market, and industrial scale, Chungnam lags behind in terms of the number of semiconductor industry employees. Chungnam ranks second in the number of semiconductor businesses nationwide (first being Gyeonggi), and third in the number of employees (first being Gyeonggi, second being Chungbuk). While the number of businesses in Chungnam continues to increase, the number of employees has significantly decreased. In summary, although Chungnam has some advantages in terms of the scale of the semiconductor industry, Chungbuk still possesses advantages in attracting semiconductor talent and environmental aspects. Furthermore, when comparing cities and regions, the spatial concentration coefficient (G coefficient) of the Incheon (Songdo) semiconductor cluster (0.01396) is higher than that of the Chungbuk semiconductor cluster (0.01388), and the EG coefficient is lower in Chungbuk. Therefore, it is difficult to determine whether a higher spatial coefficient leads to a higher level of cluster concentration. This is because it disregards the size of companies (Ellison & Glaeser, 1999).

Comparison of the Comprehensive Competitiveness of Industrial Clusters

Fig. 6 presents a graph comparing the competitiveness of semiconductor industries in the representative cities of each city and region. According to the results, Gyeonggi Province (Youngin) is considered to have the highest competitiveness score in the semiconductor industry cluster over the past three years. Chungbuk, Chungnam, and Incheon are significantly different from Gyeonggi. It can be observed that Gyeonggi's semiconductor cluster is the best in terms of cluster size and the implementation of the concept of sustainable development among all semiconductor clusters in Korea.

Figure 6. Comprehensive Competitiveness Based on the GEM-ESG Model



The reasons for this can be anticipated as follows. Firstly, the semiconductor industry in Gyeonggi Province is at the forefront in terms of scale. This reason can also be easily seen through EG coefficient analysis. Secondly, the domestic and international markets are enormous, and the export trade value of Gyeonggi Province's semiconductor industry far exceeds that of other cities (or regions) in the country. Thirdly, the research and development level of Gyeonggi Province's semiconductor industry is significantly higher than that of other regions. The semiconductor industry is an industry that places importance on innovation and creativity compared to other cities, and the level of research and development is crucial in determining value and status in the market. However, if the COVID-19 situation prolongs, the shipment volume of memory semiconductors may decrease due to the stagnation of upstream industries, and the competitiveness of Gyeonggi Province's semiconductor industry is expected to have suddenly declined in 2020 due to the impact of COVID-19 on semiconductor export contracts and equipment utilization rates. Although other regions' semiconductors have also been relatively affected to some extent, it is believed that Gyeonggi Province has been particularly affected. Semiconductor companies in Chungcheongnam-do are mainly engaged in pursuing Chungcheongnam-do semiconductor companies, and they are considered to have a stronger competitiveness than Chungcheongbuk-do or Incheon. Chungcheongnam-do semiconductor companies are actively engaged in activities such as cultivating semiconductor talents and government research support, which is increasing competitiveness. Chungcheongbuk-do initially had a lower level of semiconductor competitiveness than Incheon. However, Chungcheongbuk-do was catching up with Chungcheongnam-do in 2021. Chungcheongbuk-do can be seen as having made significant efforts to enhance competitiveness in the semiconductor industry. Incheon, when analyzing the GEM-ESG comprehensive competitiveness evaluation, has been continuously growing from 2019 to 2020, surpassing Chungcheongbuk-do in 2020, but its comprehensive competitiveness has been declining since 2020. The reasons for this are speculated to be issues such as labor supply (infrastructure), inadequate related regulations, and cluster ecosystems in Incheon's semiconductor industry.

A Comparison of GEM-ESG Indicators in Industrial Clusters

This paper aims to analyze sustainable semiconductor corporate innovation and ESG development, which are divided into three parts: E (Environment), S (Social), and G (Governance). Competitiveness scores for each city's semiconductor cluster were calculated for each level.

According to the analysis in Fig. 7, Gyeonggi Province is the economic center of South Korea with high population density and a concentration of various companies and industries. Additionally, Gyeonggi Province has well-developed transportation and infrastructure facilities, which is economically advantageous in terms of logistics and trade. Moreover, these regions have a concentration of excellent universities and research facilities, which can foster talent development and research and development activities. For these reasons, the basic indicators of Gyeonggi Province may be higher than those of other regions. According to the score analysis in Fig. 8, Gyeonggi Province has the highest innovation capacity among the semiconductor cities, which can be attributed to large-scale capital investments in technology and product research and development. In 2019, research and development investments flowing into Gyeonggi Province from the central government accounted for 11.7% of the total national research and development investment (Korea Science and Technology Statistics Yearbook). Comparing the number of patents filed nationwide in 2019, patent applications in Gyeonggi Province increased by 5.32% compared to the previous year (Korea Science and Technology Statistics Yearbook). In terms of regional research and development investment in 2019, Gyeonggi Province accounted for 51.6% (45.9 trillion won), followed by Seoul with 15.1% (13.4 trillion won), and Busan with 8.7% (7.7 trillion won). This data indicates that Gyeonggi Province (Youngin) has significantly higher corporate innovation capacity and strong actual innovation capabilities compared to other cities. Following Gyeonggi Province, Chungcheongnam-do has relatively strong innovation capacities. These two semiconductor industrial clusters continuously enhance innovation margins to increase the competitiveness of the semiconductor industry. As shown in Fig. 9, Gyeonggi Province and Chungcheongnam-do are more active in the semiconductor market compared to other cities. This is because Chungcheongnam-do is located in the central region of South Korea, and is adjacent to the capital region (Seoul and Gyeonggi Province). The geographical location of this region provides logistical and transportation convenience, making it easy to transport semiconductor wafers and components. Additionally, various research institutes and universities are located in this area, leading to active semiconductor technology research and development. Furthermore, semiconductors are essential components used in various technological applications, and the semiconductor industries in Gyeonggi Province and Chungcheongnam-do can meet domestic and international demand. In Fig. 10, it can be observed from the data that the Chungbuk region has a competitive advantage in the field of semiconductor environmental protection while promoting economic benefits in the semiconductor industry.

Fig. 7. GEM (G) Indicator Analysis

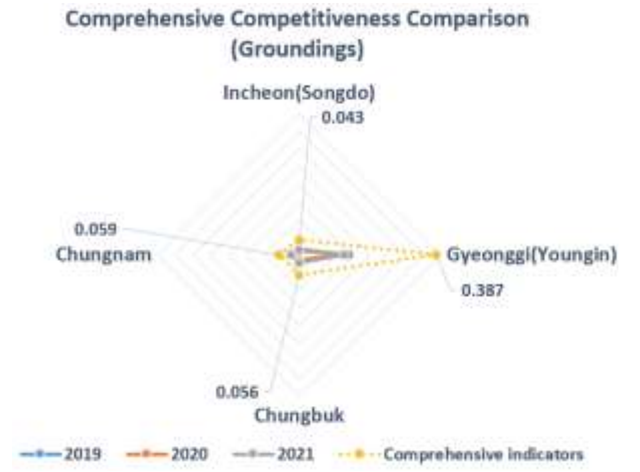


Fig. 8. GEM (E) Indicator Analysis

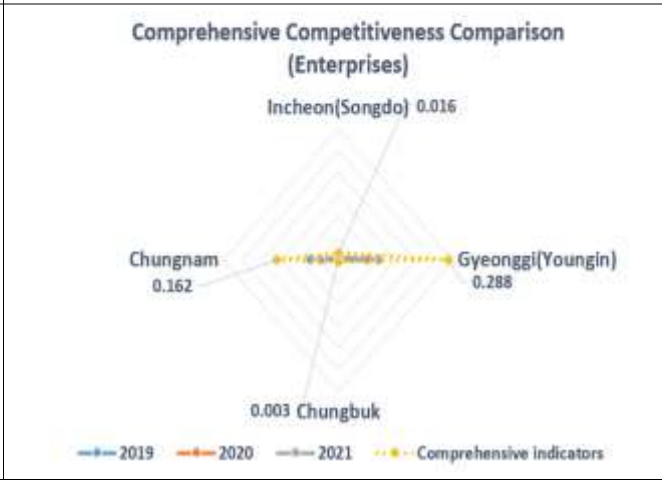


Fig. 9. GEM (M) Indicator Analysis

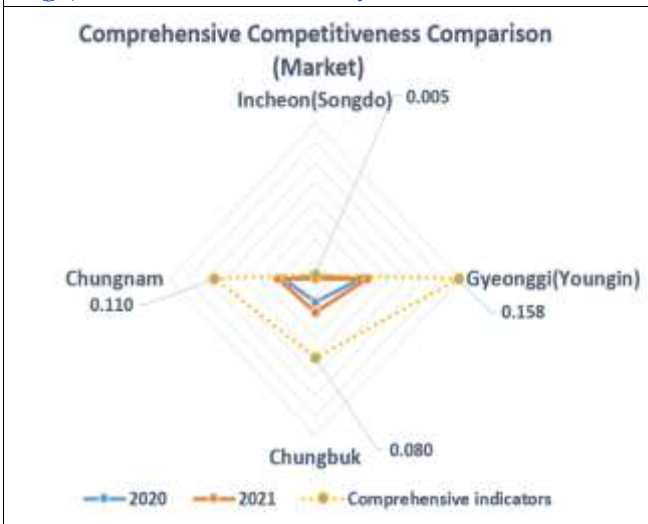


Fig. 10. GEM-ESG (E) Indicator Analysis

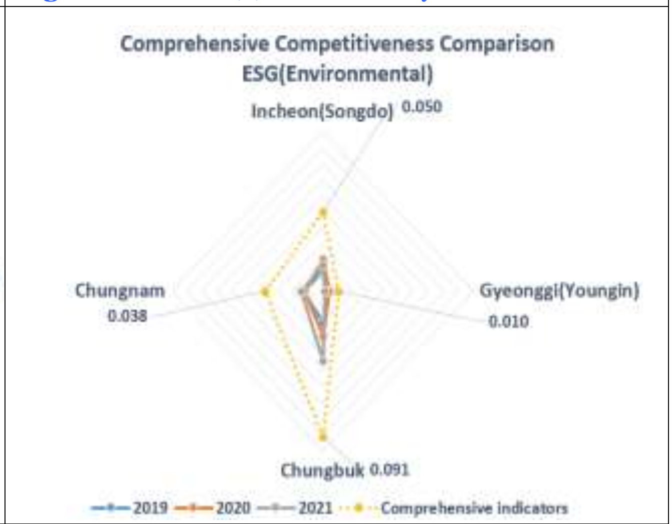


Fig. 11. GEM-ESG (S) Indicator Analysis

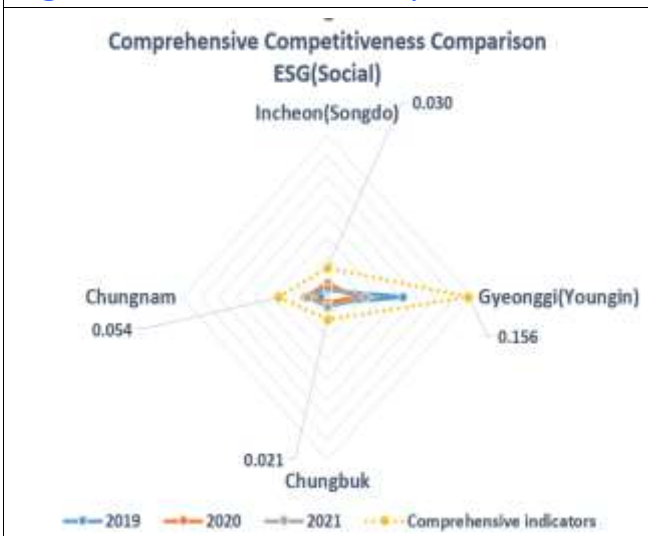


Fig. 12. GEM-ESG (G) Indicator Analysis

In Fig. 11, it can be observed that Gyeonggi has a higher level of social enterprise activity compared to other cities (or regions). This suggests that Gyeonggi is ahead in terms of corporate social responsibility (CSR) activities, and contributes more to social welfare. The government in Gyeonggi actively supports social enterprise consulting programs to enhance competitiveness. Gyeonggi province identifies and selects social contribution companies within the region, and actively promotes these to foster a society wherein people can live together. In order to activate CSR in the social aspect of ESG, Gyeonggi province has been implementing the "Gyeonggi Province Ordinance on the Activation of CSR for Public Institutions and Small and Medium-Sized Enterprises" since 2016. Fig. 12 presents the aspect of corporate governance. Gyeonggi has the highest level in terms of corporate governance indicators, such as the ratio of male to female directors and the proportion of outside directors. This indicates that Seoul has a strong competitive advantage in this area. Sound and transparent governance is an important corporate strategy in achieving sustainability. As the capital city of Korea, Gyeonggi is home to the central government and important government agencies. These institutions make efforts to maintain transparency in public service provision and policy-making. In addition, Gyeonggi has created conditions for the widespread disclosure of public information, and for citizens to access and monitor information in advance of other cities, which has contributed to greater transparency in corporate governance.

CONCLUSIONS

Discussion of the Analysis Results

Forming clusters is a highly efficient way to enhance the competitiveness of a country or region. In particular, the semiconductor cluster in Korea holds a significant position in the overall Korean economy, and therefore, the Korean government has recently promoted policies to foster clusters in key industries for national advanced strategic industries. The core industries included in this initiative are semiconductors, displays, secondary batteries, and bio-industries.

Existing research on semiconductor clusters has mainly focused on characteristics, ripple effects, and performance. However, there is a lack of empirical research comparing the competitiveness of semiconductor clusters. Furthermore, with the increasing importance of ESG during the cluster development process, enhancing the sustainable industrial competitiveness of each country's clusters has been emphasized, and demand for ESG management has also been increasing. Therefore, in this study, we investigated the ESG management activities of each regional semiconductor industry in Korea. In the process, we further developed the research model by adding ESG evaluation indicators to the existing GEM research model. We then validated the ranking of the regional semiconductor industry's competitiveness using this model.

First, based on the location coefficient and Lisa analysis results, it can be determined that the spatial concentration of the semiconductor industry in Korea, excluding Jeollanam-do, Gyeongsangnam-do, and Jeonnam-buk-do, is high. The reason for this is that the semiconductor industry has relocated to the capital region due to government policies and favorable geographical conditions. In particular, Gyeonggi-do is the central basis for semiconductor production and technological hubs, with a concentration of the semiconductor supply chain centered around Samsung Electronics and SK Hynix. Within the cluster, semiconductor companies have strengthened communication and collaboration, enabling them to learn from each other's excellent operations and management know-how, and to cooperate in expanding into overseas markets, thereby increasing competitiveness.

Second, according to the GEM-ESG comprehensive competitiveness evaluation analysis, Gyeonggi-do has a relative competitive advantage. Incheon's semiconductor industry maintained its leading competitiveness until 2019, but its competitiveness began to decline from 2020. This is due to limitations in collaboration with domestic large companies in Incheon. There were difficulties mainly related to collaboration with large company infrastructure. In addition, regarding the government's policy to foster the packaging sector, Incheon is judged to have been somewhat inadequate.

Third, through EG coefficient analysis, it can be observed that Gyeonggi-do's semiconductor industry has a higher industrial concentration compared to other regions. This is because the semiconductor industry in Gyeonggi-do has a greater influence than the overall concentration of one region. This reality demonstrates that industrial clusters in Gyeonggi-do are highly concentrated and have a radiating effect on the surrounding areas.

Fourth, looking at the ESG analysis results among the GEM-ESG comprehensive competitiveness evaluation models, Chungbuk and Incheon are considered to have competitiveness in the environmental protection and energy consumption aspects. Domestic and international semiconductor companies also use thermal oxidation to treat 90% of greenhouse gases emitted during semiconductor manufacturing to reduce environmental impact. In addition, Gyeonggi has many strengths in terms of social welfare compared to other cities or regions in terms of social aspects. This is because the role of global semiconductor company social responsibility has become increasingly important. In terms of governance, Gyeonggi and Incheon have a favorable competitive advantage. This is because the Gyeonggi and Incheon regions receive high evaluations in terms of exercising corporate legal rights, preventing corruption within companies, and fair trade.

Theoretical Implications for Scholar

This research aims to evaluate industrial competitiveness by comparing levels of industrial concentration across different regions in South Korea. The results suggest that industrial concentration is influenced not only by geographical location but also by industry scale, aligning with the findings of Ellison and Glaeser (1999). This empirical evidence provides valuable insights for future research on industrial clusters.

Additionally, the study proposes an extension of the GEM model to incorporate ESG factors into the framework to assess competitiveness. This expansion sets the stage to integrate sustainability dimensions into the broader field of competitiveness research, and encourages scholars to consider ESG factors in theoretical frameworks.
Furthermore, the study contributes to the academic community by enhancing the understanding of post-COVID-19 global trends and the impact on the semiconductor industry. It urges scholars to explore the influence of external factors, such as epidemics and geopolitical events, on industry competitiveness.

Practical Implications for Business Managers and Policymakers

Publishing the results of this study aims to provide semiconductor companies and policymakers with directions and strategies for the development of semiconductor industry and clusters. Semiconductor companies within the cluster can achieve sustainable economic growth in the medium- to long-term by sharing and collaborating on ESG values. For example, companies within the cluster can improve environment-friendly production and energy efficiency by sharing environmental policies and collaborating. Furthermore, companies within the cluster can engage in collaborative projects with the local community and seek solutions to local social issues, demonstrating social responsibility. Moreover, clusters can contribute to the establishment of corporate governance systems among companies. This is because ESG management emphasizes transparency and ethical governance. In other words, companies within the cluster can enhance trust, sustainability, and competitiveness by establishing fair governance systems and practicing transparent management.
Next, we will describe more detailed practical implications for business managers and policymakers. First is enhancing regional competitiveness. Policymakers at the regional level can utilize these insights to enhance the competitiveness of semiconductor industry clusters. This may entail making investments in infrastructure, cultivating a skilled workforce, and fostering ecosystems that facilitate innovation and sustainable development.
Second is strategic management for corporations. Managers of semiconductor companies can leverage the findings to devise strategic approaches for integrating GEM-ESG-R considerations into business models. This encompasses embracing sustainable practices, establishing collaborative networks within the cluster, and aligning business strategies with global trends.
Third is the formulation of government policies. Policymakers can employ research findings to formulate policies that bolster the sustainable development of semiconductor clusters. This could encompass creating incentives for ESG practices, fostering collaboration among industry stakeholders, and providing financial support for the research and development of environmentally friendly technologies.
Fourth focuses on strategies to mitigate risks. The study underscores the significance of ESG management in mitigating risks associated with global challenges such as supply chain disruptions. Managers and policymakers can devise strategies to mitigate risks by integrating sustainability practices, promoting supplier diversity, and enhancing the resilience of semiconductor clusters. By offering theoretical and practical implications, this study aims to bridge the gap between academic knowledge and real-world applications, providing valuable insights to researchers, industry practitioners, and policymakers alike.

Limitations and Future Research

Despite the theoretical and practical significance of this study, there are several limitations. First, during the data collection process, there was a lack of G-related indicators in the quantification of ESG. Nevertheless, it was deemed possible to objectively reflect these differences. However, if G-related variables are added in future research, more detailed analyses can be conducted. Additionally, cluster development can evolve into regional clusters, regional-interlinking clusters, and international-linking clusters. In future research, comparing domestic and international semiconductor clusters according to these stages of development may reveal more in-depth insights. Despite these limitations, the significance pursued by this study remains intact, and these limitations can be addressed as promising issues for future research.

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