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ORIGINAL PAPER

The rise and fall of industrial clusters: experience from the resilient transformation in South Korea

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Abstract

Clusters facing a crisis could have devastating effects on the economic conditions of the regions. Therefore, it is important to study how resilience works in the lives of clusters. The purpose of the current study is to more quantitatively understand the life path of the growth and decline of industrial clusters by verifying actual patterns. Also, it is to explain why these patterns were formed by qualitatively analyzing the process of utilizing resilience. The main contribution to the field of the lifecycle of clusters would be proving the theoretical concepts with data of the entire official industrial clusters in South Korea for 2 decades. Although previous works have attempted to define life paths by classifying the groups, most of their cases only dealt with one or two cases, making it difficult to generalize to a theory that can explain all types of clusters. This research used South Korean data as representative data for classification by analyzing the 1375 industrial clusters for 20 years. The trend of their life paths was calculated using a classic time-series decomposition method, and dynamic time series warping was adopted to measure the similarity between the paths. The *k*-medoids method from an unsupervised machine learning technique was adopted to classify the data. They were classified into three types: Malmo-type, Silicon Valley-type, and Detroit-type. The same classification method can be applied to other countries. Through this classification, the necessary or weak determinants of resilience in their clusters can be found. By making up for these shortcomings, continuous growth can be achieved.

JEL Classification O10 · R10 · R11 · E32

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1 Introduction

An industrial cluster is defined as a geographical agglomeration of firms, institutes, and facilities associated with a specific industry (Porter 1990). While a cluster continues to grow, another cluster declines and faces its death. In this way, new industrial clusters are constantly being created around the world. Over the years, China has developed clusters focused on numerous industries, including pharmaceutical and information technology (IT). In recent years, Thailand has steadily developed its industrial facilities, and Indonesia has experienced a rapid increase in the number of clusters under the government's active engagement. Clusters are occasionally created through cooperation between countries, as in the case of clusters in Hanoi resulting from a partnership between South Korea and Vietnam.

Industrial crisis throughout the world is exacerbated by several events, such as the global economic crisis, trade slowdown, Brexit, the US-China trade war, protectionism, and unexpected disasters, including the very recent COVID-19 pandemic. One noteworthy example is the automobile and construction industries in OECD countries stepping into a stage of decline since the global financial crisis of 2007 (Drauz 2014). Many other clusters have faced a decline by not being able to transform from traditional manufacturing to innovation-oriented, high-tech industries as well as modern business-oriented services (Bartholomae et al. 2017). With the acceleration of high-tech innovation, structural change is becoming essential, and the facilities of aged clusters, which are old and narrow, cause other problems as well. In some extreme cases, an industrial cluster could decline even further into an unrecoverable state after facing several crises.

The paths of industrial clusters are affected by crises throughout their lifetime. In the early years of studies on clusters, their life cycles have been described as a standardized form (Pouter and John 1996; Klink and Langen 2001; Zucchella 2006). This standardized form involves an aging process of birth, growth, decline, and regrowth. As this theory prevailed in the late 1900s, the main study areas focused on old clusters in Western countries. The concept of "resilience" was actively used in subsequent studies later on (Menzel and Fornahl 2009; Martin and Sunley 2011). From this perspective, the life of an industrial cluster is an evolutionary process rather than a simple and typical form. When facing a crisis, the life of each industrial cluster flows differently and draws dynamic and irregular curves while undergoing decay or regrowth.

Therefore, the life of an industrial cluster is explained better with a notion of resilience because its growth patterns are determined by how they respond to shocks (Martin 2012). In this context, the current study defines "resilience" as the ability to return to a previous state, to absorb shock, and/or to adapt to shock in a positive way (Martin and Sunley 2015). The use of resilience prevents not only catastrophic decline but also limitations to sustained growth. The industrial clusters that have a similar life pattern of increase and decrease share common determinants of resilience. Thus, identifying and utilizing these determinants can help an industrial cluster respond flexibly to any crisis.

The purpose of the current study is to more quantitatively understand the life path of the growth and decline of industrial clusters by verifying actual patterns. Also, it is to explain why these patterns were formed by qualitatively analyzing the process of utilizing resilience. It is important to study how resilience works in the lives of clusters because they function as critical economic bases for their regions, cities, and even countries.

The main contribution of this study to the field of the lifecycle of clusters would be proving the theoretical concepts with data of the entire official industrial clusters in South Korea for 2 decades. Substantial qualitative works on clusters' lives have already been conducted; however, quantitative studies that can explain the phenomenon remain insufficient. Although previous works have attempted to define life paths by classifying the groups, they have limitations. Most of their cases only dealt with one or two cases, making it difficult to generalize to a theory that can explain all types of clusters. To achieve this purpose, the life paths of clusters were analyzed in the current study based on the actual data and then categorized into groups. The reasons why patterns were formed also were analyzed according to identified groups.

In addition, the perspectives of Asian countries remain a blind spot in the literature as previous studies have mostly focused on Western countries (Hassink 2017). Even though Asia's industrial clusters have been actively growing, taking up the next leading role in the global economic arena, the previous works have been unable to prove whether industrial clusters in Asia can be explained by Western theories. Among these, South Korea is considered to be a good example as it has successfully achieved rapid growth within a very short period of time, and the key to its success is the growth of its industrial clusters. The industrial clusters in South Korea, being deeply involved in the development process, have driven the country's economic growth from the very beginning. In addition, South Korea has an optimal condition in which to compare the life paths of clusters because it has designated 1375 industrial clusters to date, which have grown under similar policies over the years.

Therefore, this study analyzed the life paths of industrial clusters in South Korea for 20 years, classified the types according to their growing and declining patterns, and analyzed the patterns that have been applied to each type of cluster.

2 Literature review

Previous works on this topic have investigated a cluster's life and degree of resilience. The studies about a cluster's life can be seen from two perspectives: life cycle and evolution. From the life cycle perspective, the cluster's life is an aging process. From the view of evolution, the cluster's life dynamically flows as it encounters events and crises.

The life cycle perspective has been used as a basic idea to explain a cluster's life since the 1990s. This view defines a cluster's life as an aging process from birth to death. It generally has four phases, although one or two phases have been described differently in various ways: (1) birth or development, (2) growth, (3) saturation and stagnation, and (4) decline or regrowth (Porter 1998; Pouter and John 1996; Klink and Langen 2001; Zucchella 2006). However, the life cycle perspective has a

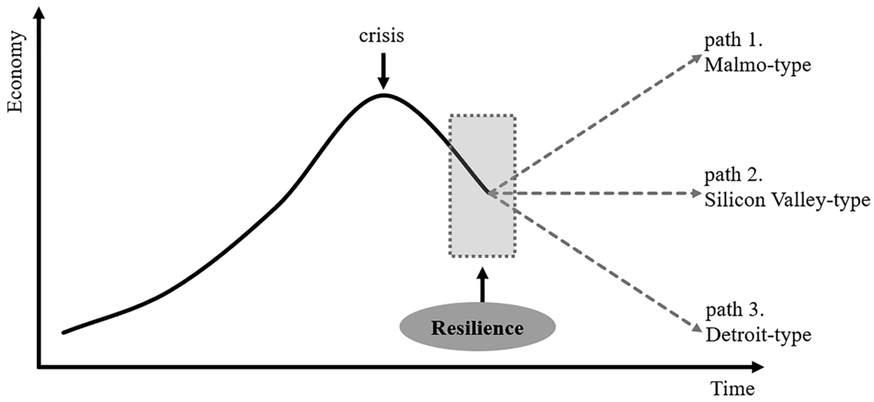


Fig. 1 Possible life paths

limitation in that it examines a cluster's life following the aging timeline so it cannot be used to explain exceptions that do not follow the process.

The idea of industrial clusters evolving through a series of crises dominated the late 2000s (Menzel and Fornahl 2009; Martin and Sunley 2011). These studies still admitted that clusters could follow the four basic stages of the life cycle, but clusters change their paths dynamically as clusters undergo success and failure through various crises, such as internal and external problems, breakaways of firms, and a lack of competitiveness. Martin and Sunley (2011) explained the process of evolution as having six possible paths: (1) four basic stages of the life cycle and then replacement by a new cluster, (2) constant innovation, (3) stabilization in the particular state, (4) re-orientation of specialism, (5) failure, and (6) disappearance. According to this perspective, resilience helps a cluster overcome a crisis.

The life paths of clusters are profoundly involved with resilience in a way that it shifts paths after running into a crisis. The concept of resilience has received considerable attention from numerous fields of study, individuals, markets, and countries, so the definitions provided differ in each field. A clear explanation of how resilience works in regional economies was found in what is considered representative research in this field, Martin (2012) and Martin and Sunley (2015). This explains how resilience affects firms' potential paths, and it can also be related to clusters' paths. Martin's (2012) work analyzed the ways in which UK cities respond to regional recessions, namely, resistance, recovery, change, and improvement. Martin and Sunley (2015) have argued that regions react differently to a crisis because the conditions of each region are divergent.

Three possible paths are distinguished in this study after running into a crisis (Fig 1). Representative examples were used to indicate the paths more familiarly. The clusters of each type used resilience in their own different ways. The first path is the Malmo-type, which shows a re-leaping pattern. The clusters of this type struggle with a short-term loss after a crisis but regrow in the long run. Martin (2012) explained this type as a positive hysteretic reaction that the regional economy rebounds more than the pre-shock growth rate, which sometimes leads them to initially experience rapid growth. A typical example is Trafford Park in the UK, whose manufacturing industry suffered a decline but experienced regrowth after a long period of time. Sheffield in the UK also suffered a decline of its old city center along with unemployment due to a decline in the steel industry; however, it eventually succeeded in transforming itself into a cultural industrial city.

The second path is the Silicon Valley-type, which is able to maintain a current state. Martin and Sunley (2015) described this type as returning to its pre-shock growth pattern. It does not always bounce back to the previous growth rate, but it certainly shows regrowing patterns. In this type, a cluster returns to its previous state not long after it experiences the shock of a crisis. As it returns to its previous state, it could go two ways: it could neither increase nor decrease, or it could continue to increase if it used to increase before the incident. Most firms that reached a stagnated phase hardly accept new firms into the cluster (Qstergaard 2015), which prevents them from further growth. However, Silicon Valley, as an example, keeps forming its network with new entries and it allowed them to continuously grow (Kenney, 1999).

The third path is the Detroit-type, which shows a decreasing pattern. If shock is severe enough, the permanent effects on the growth pattern will prolong (Krugman 2009). Martin and Sunley (2015) found it happening in the long run when it failed to reorganize or restructure its industry. A cluster does not recover and continues to decline, even after some period of time has passed. In extreme cases, a decline in a cluster could lead to a corresponding decline in the region and city where it belongs. Even an industrial cluster that once flourished could end up being this type if it suffers from stagnation. Two major examples are the decline of the Detroit automobile industry in the US, which caused the decline of the entire city (Bukowczyk 1984), and the downturn experienced by the large-scale maritime industry of Imabari in Japan.

The clusters in each type of path described above share common determinants of resilience, namely, industrial structure, human capital, government policies and support, and location (Table 1). By properly utilizing these determinants, the clusters can successfully have either the Malmo- or the Silicon Valley-types; otherwise, they will end up having the Detroit-type path.

First, the structure of the industry in a cluster influences its resilience. A cluster could easily restructure to another industry when it has industrial diversification. The dichotomy of economic specialization and diversity has been controversially discussed in the previous literature (Marshall 1890; Porter 1990; Glaeser et al. 1992). However, diversification is a substantial condition for growth (Jacobs 1969), whereas a lack of diversity leads to a cluster's decline (Menzel and Fornahl 2009). A key element in increasing diversity is embracing new entrants to clusters and accepting new technologies and modes of development (Menzel and Fornahl 2009; Qstergaard 2015).

In the Malmo-type path, industrial restructuring is a critical determinant to overcoming a crisis. Clusters' economy can be restored through changes in the industrial structure (Martin and Sunley 2015). For example, Hong Kong has overcome industrial stagnation by promoting changes in the industrial structures of its clusters (Young 1992) from manufacturing to the service industry. By taking stagnation as a

Table 1 Determinants of Resilience

Determinants of resilience	Industrial structure	Human capital	Government policies and support	Location
Description	A diversified industry has a tendency to be resilient because it has an economy that is easier to back up by restructuring itself into other industries	A strong network built among industry, research, and academia can benefit one another with information change and a qualified labor pool	Government policies that provide support, such as financial benefits and deregulation, increase the resiliency of the clusters	Having a location that favors high accessibility to amenities and infrastructure makes the clusters resilient
References	Porter (1990), Porter (1998), Menzel and Fornahl (2009), Martin (2012), Martin and Sunley (2015), and Qstergaard (2015)			

turning point, the new clusters focused on global trade, logistics, and finance, and in a few years, business services grew successfully on a global scale.

The previous cases of failure having a single industrial structure when the cluster collapses, becomes unstable, and/or causes massive unemployment. The concept of the anchor firm (Kuchiki 2004) is a large, attractive firm that draws other related firms to its clusters. Then, these clusters grow positively together as they focus on major industries and become dependent on the anchor firm according to the so-called "background linkage effect." However, a crisis could easily reverse this positive effect, which would then have a series of negative effects on the firms in the cluster. The city of Imabari in Japan was famous for having one of the largest maritime industries in the world. However, its shipbuilding industry was intensely stagnated by the Plaza Agreement in 1985, which deteriorated its export competitiveness. Subsequently, stagnation in the manufacturing sector in the 1990s, followed by a collapse of the economic bubble, led to a long-term recession.

Second, the formation of strong human capital strengthens resilience. The number of skilled and qualified employees who remain in a cluster after a crisis determines its resilience (Martin and Sunley 2015). When clusters struggle with a crisis, the first thing they would do is either reduce employment to recover their financial status or allow employees to leave and look for better jobs. But Boston's successful growth story of reinvention three times through repeated recessions shows human capital takes a considerable role in resilience (Glaeser 2005). It is critical to maintain talented employees because they are important assets for technology implementation, information collection, and network building.

The determinant of human capital is often used for the Silicon Valley-types of paths. Industrial clusters on a solid growth trend have strong networks among industries, academies, and institutes. To ensure the growth of a cluster, it is important to have an influx of qualified workers looking for jobs or wanting to start their own firms. Information exchange and innovation help strengthen the network, which in turn, enables the clusters to maintain long-term competitiveness (Saxenian 1990).

For example, the three top bio clusters in the US, such as Silicon Valley, San Diego, and Boston, have been continuously growing, thanks to their well-established network systems starting from researchers all the way down to production (Yoon 2007). Research-oriented academic institutions, such as California State University and Harvard University, are cradles of the bio-industry and are known as the driving forces behind its continued industrial development. Meanwhile, Osong Bio Valley in South Korea, built on the combined grounds of research, production, and administration by the government, has experienced continuous growth by actively conducting joint studies for 10 years (Yoon 2007). The bio-industry tends to have a higher connection with basic research institutes, including universities, than other industries, and most of their firms are geographically clustered, with prominent universities collaborating with them.

Third, government support and intervention contribute to a cluster's resilience. Resilience is influenced by government strategies, policies, regulations, and support (Martin and Sunley 2015). Although government's long-term involvement in the market could result in a negative impact, it legally helps them flourish their industries (Porter 1990). Government deals with the problems that the market cannot solve on its own, and as a result, the industrial structure changes depending on the government's plans.

Especially, Malmo-type would be difficult to transition to another industry without government support. It is difficult for small enterprises to change the entire industrial structure within their clusters when their main industries face a downturn due to a crisis. It has been shown that government intervention has a substantial impact on industrial growth and structural change (Lee and Jung 2020), as shown by the example of Singapore and Hong Kong (Wang 2018). Also, the government of South Korea provided an amicable trading environment with tax subsidies and political support for its export-oriented clusters, which then exported a wide range of products to hugely boost Korea's economy (Kim 1999). When another problem emerged from the light industry's downturn in South Korea, the government responded by moving on to heavy industries and establishing large clusters.

To alleviate the impacts of crises, governments mitigate regulations, offset export incentives, and expand subsidies for export-oriented clusters (Auty 1994). Clusters that depend greatly on exports are vulnerable to changes caused by external events and can certainly use their government's support. For instance, most East Asian countries have grown dependent on exports due to scarce resources (Auty 1994). Their export rate to GDP is so high that some cases even exceed 100%, according to World Bank (2019), while the US, a representative country for high domestic demand, is just around 10%. Indeed, the US can still experience shock from global crises, but the impact of such a shock on the country would be relatively smaller than that on export-oriented countries. On the other hand, East Asian countries have frequently undergone unexpected external events. Korea and Japan, for example, adopted policies on technology subsidies and low-interest rates to foster export-friendly environments (Akkemik 2008). This helps clusters achieve financial stability when facing a crisis and operate within industry-friendly environments.

Finally, industrial clusters in good locations are more resilient than those in not-so-ideal locations. Martin and Sunley (2015) insist the difference in resilience across regions can contribute to patterns of long-run growth. Location remains an important factor, even though globalization and the new industrial revolution have reduced constraints related to location (Porter 1998). In the current study, good location means accessibility only in a way that avoids redundancy with other determinants of resilience.

The firms prefer to be located in areas with high accessibility to amenities such as restaurants, nightlife, culture, and sports complexes (Kimeleberg et al. 2013). Having good accessibility also means that clusters take advantage of transportation costs because industrial materials are easily conveyed in and out, thanks to the favorable location. The Seoul Digital Industrial Complex (G-valley) also has a substantial advantage by being located in Seoul, thus supporting its consistent growth. In summary, clusters located in metropolitan areas are definitely in high demand among potential firms and workers.

Also, people favor visiting locations with developed infrastructure, such as those with highways, parks, sports facilities, and cultural venues. (Florida 2003). Most people prefer to work in metropolitan areas, where they are guaranteed excellent access to transportation and an attractive environment for business. For example, Paju Book City, an industrial cluster in South Korea, is located far from metropolitan areas, thus imposing a limit on its growth trend due to the inconvenience of commuting there. In comparison, Pangyo Techno Valley, which is located near metropolitan areas, has an optimal condition for attracting human resources, particularly young people (Chung et al. 2017). Thus, it has seen continuous growth in recent years.

The determinants of resilience mentioned above can work individually, but they often work when combined with other determinants. When they exist together, they can produce a more positive effect. For example, although industrial restructuring is an important condition for the Malmo-type path, achieving this would be difficult without government support. Henceforth, this study examines how resilience is involved in a cluster's growth according to each type of path discussed in this section.

3 Research methods

This study follows the procedures depicted in Fig. 2. The first step is a literature analysis of a cluster's life and its resilience process. The second step is the classification of a cluster's life paths using data from South Korea as a representative case. The classification involved the following steps: data preprocessing, analysis of time-series trends, measurement of similarities between time-series data, the grouping of time-series data, and finally, analysis of the resilience process occurring in each group.

The representative and quantitative indicators that can explain the growth and decline of industrial clusters with resilience include the number of employees, the total cost of production, and the total cost of export in clusters. These indicators are the evident indexes that demonstrate whether a cluster is growing or declining. These indicators have been affected by clusters since their establishment as they bring economic changes (Kim and Lee 2012). Most previous quantitative studies have used these indicators as indexes for economic growth. South Korea has steadily accumulated data on these indicators for 20 years; we can use such a dataset to demonstrate growth and decline along with the history of clusters in the country.

Therefore, all three indicators mentioned above were used in this study to analyze patterns of clusters' life paths. The first indicator, the number of employees, explains changes in the cluster populations. A decline in employment implies that the number of job opportunities is decreasing, which would eventually affect the city population where the clusters are located. As stated in a previous study, employment in clusters is related to productivity in a city (Bartholomae 2017). The second indicator, the total cost of production, explains the productivity of clusters by presenting whether the firms in the clusters are currently operating. The last indicator, the total cost of exports, represents vitality, as a decrease in the total cost of exports indicates a decline in clusters. This is especially observable in a country like South Korea, which mostly consists of export-oriented industries.

The changes in time-series data as they increase or decrease determine the degree of growth or decline, respectively. In relation to these, resilience was investigated

Fig. 2 Research procedure

accordingly in this study. When a decrease was identified, its historical background in the past few years was investigated to determine what had caused the decrease. For example, when the global crisis of 2008 hit every cluster in the world, most clusters' life paths declined, as revealed in the data. Resilience normally works as a response to a crisis, and the figures would be increased if resilience worked out positively.

The data of 1,375 industrial clusters were retrieved from the Korea Industrial Complex Corporation (KICC) (2001–2019). It included all previous and current data under the KICC's control, such as all the clusters that are currently not on the KICC's list. Through data refinement, 800 industrial clusters were finally selected. The missing data removed by KICC when it went below the specific number were excluded. Selection Bias might occur since it cannot explain the clusters with very low profits. Thus, time-series data accumulated for almost 20 years from 2001 to 2019 were used in this paper. The data were recorded in the last months of every quarter, namely, March, June, September, and December. The refining process was carried out in three steps. First, the status of the designation was confirmed through the Industrial Land Information System, local government websites, and their official news. Second, the changes in names over time were tracked down and corrected. Third, overlapped data were separated, incorrectly combined data were reorganized, and incorrect data were revised. The units that were recorded differently were also unified into employment (persons), production (billion won), and exports (million dollars).

The trend of life paths was calculated using a classic time-series decomposition method, namely, the moving average (MA). The MA is a commonly used calculation for the analysis of stocks and investments when data are too complicated to recognize a trend, mainly due to the periodicity of time-series data. Using this method, a new data point was generated by a series of averages of different subsets of the full data set until a trend in time became reasonably recognizable.

$$MA = \frac{1}{m}\sum_{j=-k}^{k} y_{t+j} \tag{1}$$

In the MA equation, shown in Eq. (1) above, k represents a period of time, m is the size of subsets, and y_{t+j} is the value at $t+j$ of the time-series. In brief, subsets of the full dataset are added and divided by the size of subsets, and this process is repeated until all the subsets are averaged. In general, a subset of MA is obtained using odd numbers, such as three, five, and seven, which are more likely symmetrical in data. However, the data of the current study replicated similar patterns in every fourth quarter, and the trend was more smoothly displayed with four; thus, four was used for the size of the subset. The MA makes the original curve smoother so that the trend can be depicted without distortion.

Once the MA was calculated for every life path, dynamic time series warping (DTW) was adopted to measure the similarity between the paths. DTW is an algorithm that measures the distance between two graphs, and the measured distance determines the degree of similarity between them. Since its introduction by Berndt and Clifford (1994), DTW has been used to distinguish human voices by identifying their patterns and shapes. It is also widely used for pattern analysis of time-series. Especially, it is known as the most accurate method of measuring the similarity of time-series data (Wang et al. 2012). DTW is able to overcome the shortcomings of the Euclidean distance method in that Euclidian distance cannot compensate for a distorted or deformed waveform, whereas DTW can find the minimum point in such a form and match it appropriately (Keogh and Pazzani 1999). The calculation of DTW is conducted using Eq. (2):

$$\mathrm{DTW} = |Ai - Bj| + \min\left(D\left[i-1, j-1\right], D\left[i-1, j\right], D[i, j-1]\right) \quad (2)$$

where Ai and Bj stand for each graph's values, respectively, and D stands for the distance between the two points. Through $|Ai-Bj|$, a difference between two graphs was measured first, after which the minimum number among the previous values was added.

The DTW algorithm typically cooperates with the *k*-medoids method, which is a clustering algorithm that classifies graphs. It is an unsupervised machine learning technique that can classify data based on the similarities found. It is similar to the *k*-means algorithm, which is a more common method for classification. However, *k*-medoids has an advantage over *k*-means in that the former can more sensitively recognize outliers of data because it chooses the actual data points as centers to measure similarities, whereas the latter chooses the averaged points as centers. The *k*-medoids algorithm proceeds in the following order: (1) selecting random data as centers, (2) measuring the distances between the entire datasets and the centers, (3) allocating the data to the closed centers, (4) marking them as a group, (5) calculating the total distance and the so-called total cost, and (6) repeating the steps until the total cost is at a minimum.

4 Result: classification

Historically, the South Korean economy has shown an outstanding growth curve among other Asian countries because of its rapid growth in a short period of time. Clusters in South Korea have led its economy from the early stages of its growth, so they are deeply involved in its development. So far, a total of 1375 clusters have been created and designated under government control, and the same industrial policies, such as tax incentives, have been applied. While these other conditions were controlled, this study classified their life paths and examined the ways in which resilience worked in this context.

As mentioned in the research method section, South Korean industrial clusters were categorized into three groups according to their life paths: Malmo-type, Silicon Valley-type, and Detroit-type. The classification was drawn out by DTW and k-medoids by considering how resilience works in these paths. The analysis was carried out using the Python, which is widely used for data analysis and machine learning. Scikit-learn is the primary library used in the analysis. In a typical machine learning method, 70% of the data is used for training and 30% for testing. Therefore, 70% of the randomly selected data from each section, exports, production, and employment were used for training, and 30% of the data was used for testing. The corresponding accuracy calculated is 93% in exports, 91% in production, and 87% in employment.

In the Malmo-type path, a cluster overcomes a big crisis and grows afterward. It uses two or more determinants of resilience when facing a crisis. In the Silicon Valley-type path, a cluster periodically repeats a cycle of growth, stagnation, and decline, but it maintains a good working state in the long term. This type uses human capital as a form of resilience. Finally, in the Detroit-type path, a cluster gradually shrinks and loses its vitality. Under this path, the cluster does not make good use of the conditions of resilience.

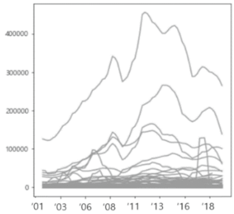
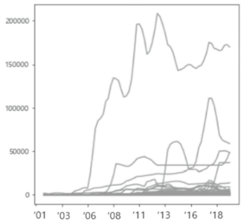
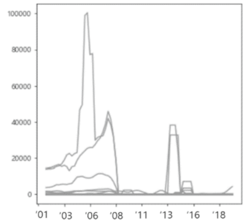
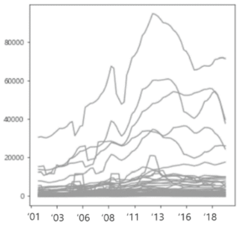
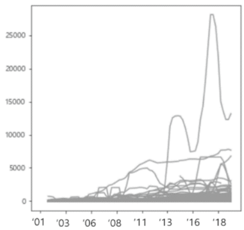
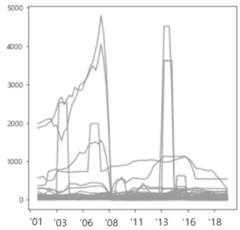
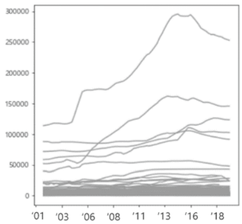
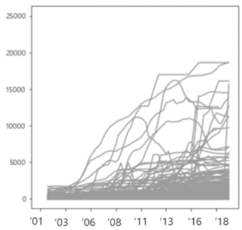
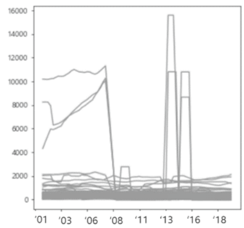
4.1 The Malmo-type

A cluster that has a Malmo-type path draws a curve that regrows after a decline. As a result of the analysis, the total number of this type is 496, which is 64% of the South Korean industrial clusters. This type even experienced a huge recession like the IMF before 2001, then it rapidly increased by overcoming it as Martin (2012) described initial rapid growth after a shock. They faced several crises afterward, as it is clearly shown in the time-series graphs of the exports amount and the production amount in Table 2, but it had increased steadily until around 2015 when the overall Korean economy took a downturn. The employment rate had a few steady states in the meantime, but it had also been continuously increased until 2015. Exports took a huge role in the economic growth in Korean history, but the growth slowed because the rapid expansion of exports was no longer feasible.

Malmo-type path overcomes a crisis by potentially using all the determinants of resilience, including restructuring, government support, human capital, and location. It fits in the description as Martin and Sunley (2015) mentioned that this type of path overcomes crisis and regrows again by changing its specialism. In the real world, as the graphs show that before they regrow, this type faced turbulence multiple times, and it could not avoid the mega trend of downturn happening in the country in the last five years.

The best example is Malmo, which overcame the crisis and turned over the situation. Malmo is a cluster in Sweden wherein the Kockums shipyard drove its economy. It is located in the North and Baltic Sea, which serves as transportation hubs, leading to the successful development of the local shipping industry back then. However, the so-called “Tears of Malmo” occurred, and the industry was devastated by a loss of its global competitiveness; furthermore, oil shocks occurred in 1973 and

Table 2 Classification

Type	Malmo-type	Silicon Valley-type	Detroit-type
Diagram			
Description	-It overcomes a temporary crisis and rapidly grows afterward. -The global crisis caused stagnation or decline in the last few years.	- It continues to grow since its birth. -It could repeat growth, stagnation, and decline, but it is able to maintain its state in the long term.	-It overcomes some crises in the short term, but it clearly declines in the long term. -The amounts of production and exports, as well as the number of employees, are significantly lower than in other types.
Exports (million dollars)			
Production (billion won)			
Employment (persons)			
In total	496	125	148
Example	G-valley	INNOPOLIS Daedeok	Gunsan

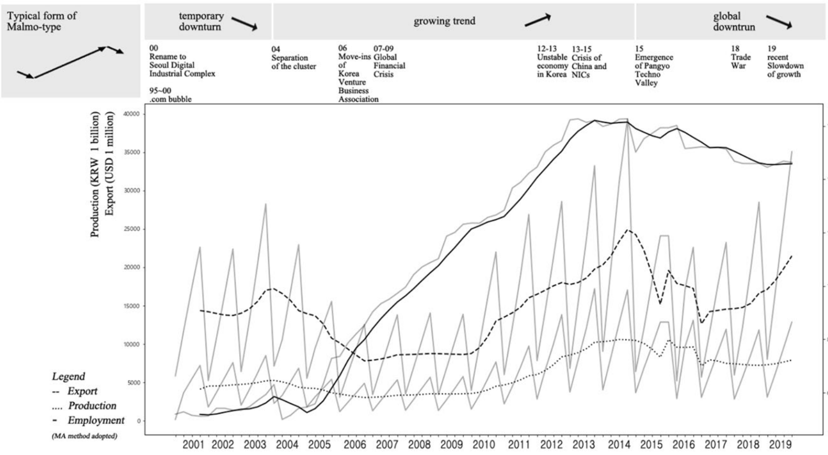


Fig. 3 Time-series data of the G-valley

1978. To restore the economy, the Swedish government and Malmo have fostered a knowledge-based and high-tech city centered on IT, media, and biotech since 1994. It has successfully nurtured human resources from Malmo University, supported start-ups through cooperation between the industry and the university, and eventually transformed into an eco-friendly city. Currently, Malmo has attracted highly educated young people to its employment pool (Hsiung 2014).

Meanwhile, the Guro Industrial Cluster (GIC) shows a Malmo-type path as well (Fig. 3). Over the years, it was able to regrow rapidly after a crisis with strong government support and restructuring efforts delivered at the right moment. It had driven the early industrialization and economy of South Korea by focusing on the export-oriented and labor-intensive light industries, such as textiles and clothing, based on the government's policy since the 1960s.

The GIC has undergone several crises over the years. As the previously dominant light industry declined in the 1970s, the government restructured its main industry into heavy and chemical industries, such as machinery, electronics, and chemistry. However, this economy started going downhill after the peak of exports in 1988 due to the social phenomena of avoiding the 3D (dirty, difficult, and dangerous) industry and rising wages. The IMF financial crisis in 1997 caused the bankruptcy of major companies within the cluster. The cluster's deterioration also became a huge concern for the government because it would affect the local economy and job market. Thus, the government came up with the "Guro Industrial Cluster Modernization Plan." This plan drastically conducted deregulation, which allowed research institutes and venture companies, aside from factories, to move into the cluster. Moreover, this plan led to an industrial restructuring into the high technology, fashion design, and knowledge industries. In 2000, the name GIC was changed to "Seoul Digital Industrial Complex", also known as G-valley.

Another period of change came along as the speculation craze of the "dot-com bubble" in the early 2000s dwindled. As the dot-come bubble ended, IT companies that had been clustered in the Gangnam area, which is the largest IT industrial cluster in Korea, were dismantled, and only the skillful companies survived through it. In fact, this period turned out to be an opportunity for the G-valley. Its merits were considered attractive by many companies, so it became another strong cluster. It had excellent accessibility and a good transport network, which was comparable to those of Gangnam, but at the same time, the price of land and the cost of maintenance were lower. Furthermore, there were only a few restrictions on the expansion of factories or the establishment of corporations even though they were located in Seoul, which had strict regulations at that time. Apartment-type factories were excluded from the regulation policy of total factory number management in the metropolitan area (Total Allowable Factory Construction Act, 2004), and it allowed more apartment-type factories to be populated in the G-valley. The new cluster achieved growth by allocating spaces for small and medium-sized companies and by receiving support from the government and other major companies. Moreover, the government supported the move-in of the Knowledge Industry Complex into the cluster and provided tax benefits, deregulation, and low-cost operations. Since then, the G-valley has continued to grow rapidly, especially as it is considered a highly attractive cluster that has drawn great interest from many young people.

Although the trend of its life path seemed to have decreased since 2004, this could be attributed to the separation of the clusters. The KICC used to record the data of the G-valley with those of Juan and Bupyeong under the name of "Korean Export Industrial Complex" in the sections of total exports and production. Therefore, it was not an actual decrease; rather, it kept growing instead. As the Korea Venture Business Association relocated into the G-valley in 2006, it extended its support for venture companies.

Inevitably, the G-valley faced several crises afterward. While the global financial crisis from 2007 to 2008 slowed down the South Korean economy, most clusters survived decreased exports, which led to subsequent reductions in production and employment. Yet, despite the overall economic downturns and declines, employment in the G-valley continued to increase. Between 2012 and 2013, when the economy was unstable due to export stagnation in the manufacturing sector, domestic economic stagnation, and shrinking investment sentiment, the figures related to exports, production, and employment continued to increase. However, the appearance of a competitor, Pangyo Techno Valley, in 2015 brought a big blow to the sustained growth of the G-valley. Even though the G-valley was located in one of the most accessible areas among the industrial clusters in Seoul, Pangyo Techno Valley was more advantageous in many ways. In particular, it is geographically adjacent to Gangnam, Seocho, and Songpa-gu, which are knowledge-based industrial areas; it is also adjacent to Seongnam, Ansan, and Incheon, which have strengths in high-tech manufacturing (Chung et al. 2017). As a result, the G-valley started to decline, losing its competitiveness in terms of cost advantages. Production and employment also showed downward trends due to the trade war dispute in 2018 and the recent downturn in the global manufacturing sector. In response, the G-valley recently devised a countermeasure to attract young people by expanding space and building support facilities, such as rental housing, for start-ups.

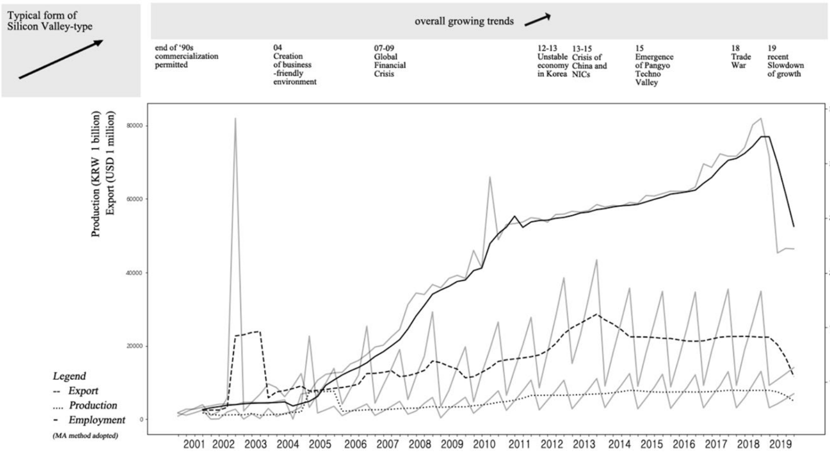


Fig. 4 Time-series data of INNOPOLIS Daedeok

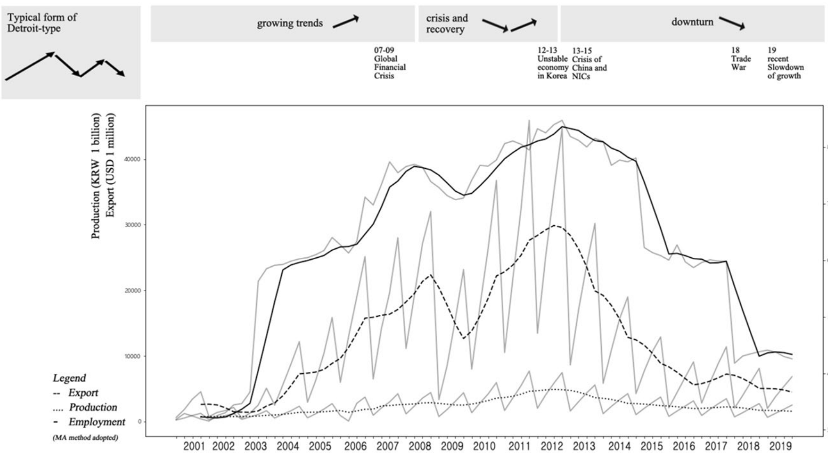


Fig. 5 Time-series data of Gunsan

The Malmo-type path shares common characteristics. It focused on restructuring an industry facing a crisis under strong government support; it also aimed to attract a young population by using its geographical advantage. This crisis caused a temporary decline, but what makes this type different is that it eventually achieved a regrowth phase after overcoming the crisis.

4.2 The silicon valley-type

The second path is the Silicon Valley-type. As a result of the analysis, the total number of this type is 125, which is 16% of the Korean industrial clusters. As Martin and Sunley (2015) described this type, the graph shows the pattern bounced back to the pre-shock growing rate. It has obviously been challenged by several downturns, such as the global financial crisis, from 2008 to 2009, but the overall trend is upward even after the year of 2015, the economic downturn in South Korea. The employment rate also showed it bounced back to the pre-growth rate after a shock.

This type of path shows a periodical repetition of growth, decline, and stagnation, that is, a cluster overcomes its problems and rises again when faced with a crisis instead of experiencing a decline or collapse. Therefore, frequent crises might occur, but they do not cause rapid changes in the cluster. A cluster may rise and fall repeatedly, but it will not remain in one phase (i.e., either growth or decline). This type of path uses human capital as a major determinant of resilience and establishes strong cooperation among industry markets, academies, and research institutes.

Resilience here is mainly driven by human capital and government support, along with other factors. This type proves that forming strong human capital strengthens resilience, and the representative example of South Korea stayed in a strong growth pattern thanks to the formation of this network. Therefore, the best example is Silicon Valley.

The human capital determinant greatly contributes to Silicon Valley's resilience. As an icon of IT cluster success, Silicon Valley began its journey in 1891. Its resilience was built during the early years when it was developed to attract highly qualified workers to prevent them from spilling onto the Eastern coast. Silicon Valley's continued growth stems from its social network (Saxineton 1990). In the beginning, it formed a strong bond between the industry and academia through a well-connected system between virtuous workers and Stanford University. This social network became a huge labor pool through frequent employment and turnover in the same field, activated by workers sharing their experiences with one another and openly communicating with new entrant firms. Its resilience was tested when the growth of Japanese semiconductors in the 1980s threatened Silicon Valley. Although some companies failed, the majority managed to upgrade their technology by exchanging information through social networks. Firms jointly invested in essential consulting, network services, and market studies that each individual company could not afford. Despite the recent decline in the US population today, Silicon Valley has contributed to job creation and maintained a continuous inflow of foreign population. It specializes in major industries, such as hardware, software, Internet services, and biotechnology.

In comparison, INNOPOLIS Daedeok in South Korea has become resilient through social networks formed on government-led and university-based research. During its development period from 1974 to 1993, it was the largest R&D cluster in South Korea, with three government agencies, 15 government-funded research institutes, four government investment institutions, and three universities within the cluster (Hwang et al. 2018). Until the end of the 1990s, it was characterized only as a research center because its research results were not entirely commercialized (Lee and Chung 2014). Through collaboration among the industry, academe, and research institutes, commercialization was allowed by the late 1990s when the "INNOPOLIS Daedeok Management Act" was revised; this was a government-led effort to build business-friendly infrastructure in late 2004 (Hwang et al. 2018). This context explains the explosive increase in production and exports in the cluster since the 2000s (Fig. 4).

Since 2005, INNOPOLIS Daedeok has maintained its growing trend without facing a huge shock by expanding space based on the efforts exerted by the national government and the Daejeon Metropolitan City government. Under the "Special Act on the Development of a Special R&D Zone," it became the first dedicated research and development zone of its kind within the country. Guided by the goals of commercializing its research outcomes, creating a business-friendly environment for ventures, building a global environment, and establishing more networks with other regions, its production volume has rapidly increased over the years.

Nevertheless, there was also a temporary decline in the life path of INNOPOLIS. For example, as the cluster's successful exports depended on other countries, it temporarily declined during the global financial crisis of 2007–2008 and the economic crisis of 2015. In contrast, production and employment steadily increased. Employment rates, in particular, increased rapidly from 2010 to 2011. Afterward, its growth continued through the expansion of networks and the diversification of intermediate organizations (Hwang et al. 2018). However, since 2018, its growth rate has shown a decreasing pattern due to the global economic slowdown and a decrease in the value-added rate.

Another cluster that belongs to this type is the Osong Bio Valley, which is dominated by firms engaged in the manufacture of medical materials and pharmaceuticals. Just like INNOPOLIS Daedeok in its early years, it has shown continuous economic growth. The Osong Bio Valley has specialized in the bio-industry since 1997, successfully integrating research, production, and administration through the support and promotion of the government. Its key to success is its strong social network among public institutions, research institutes, and companies. Osong Bio Valley also established a research connection with Chungbok National University's pharmacy college and research center within 600 m, as well as other universities such as Korea Advanced Institute of Science and Technology and Chungnam National University, which are 40–50 km away.

4.3 The detroit-type

The third path is the Detroit-type. As a result of the analysis, the total number of this type is 148, which is 19% of the Korean industrial clusters. The severe shock caused a permanent decline (Krugman 2009). According to the graphs, the industry did not break down or decline at once. It went down a path of deterioration after it went through several harbingers of decline. It might have been able to overcome it during the first time of recession, but it was hard to conquer all the hardships. The amounts of exports and production were upwards until 2008 for most of the cases, and then they dropped to almost zero in few cases. Several years later, they were able to overcome the obstacle. However, 2015 was a crucial time for every cluster, especially for those who had just overcome the deficit a few years before that, so they declined.

The clusters considered to have the Detroit-type path have a tendency to decline due to their poor utilization of resilience. One common problem with this type of path is the single industrial structure. Focusing on a single industry was an advantage in the early days of cluster formation, but it could occasionally bring fatal consequences, depending on how they dealt with it. This type of path experiences multiple crises, but it is unable to fully recover from each one and the subsequent crises that come their way. Therefore, this kind of cluster continually shrinks, loses its vitality, and eventually declines. In extreme cases, the crisis results in a decline that affects not only the cluster but also the entire city or region. Detroit, a well-known cluster in the US, for example, failed to overcome several crises in the automobile industry and eventually faced its downfall. Detroit was once the largest industrial city in the US in the 1800s and had a great run with Ford, GM, and Chrysler during the 1900s. Since these were large factories, workers rushed to the cluster from all over the region, resulting in a great increase in population and the city's development as well. However, after the industry peaked in 1950, the outflow of the population began. The rising competitiveness of the manufacturing industry in late-comer countries, the emergence of Japanese cars with a cost advantage, and the increased wages of employees in the cluster triggered a crisis in the US automobile industry. In addition, the Detroit riots in 1967 resulted in a massive outflow of the population, which then reduced the tax base and made it increasingly difficult to support urban infrastructure and mitigate the increasing rates of building vacancies. Detroit started from being in an advantageous location surrounded by the Great Lakes, which was best-suited for amphibious transportation. It eventually became difficult for the cluster to overcome the industry's downturn.

Among Korean clusters, this type of path is often found in those clusters that are highly dependent on large companies. Since Korea started focusing on the heavy and chemical industry, it has become the center of the shipbuilding industry in the world. Britain and Japan, which were formidable in the early years of shipbuilding history, faced declines in their industry as a result of various incidents and the loss of their competitive advantages. The Korean government took this opportunity to focus on the shipbuilding industry as a national strategic industry. In the 1970s, clusters in the shipbuilding industry were created, and large corporations were established. Those clusters and corporations included Gunsan and Hyundai Heavy Industries (established in 1972), Okpo and Daewoo Shipbuilding and Marine Engineering (established in 1973), Jukdo and Samsung Heavy Industries (established in 1974), and Jinhae national industrial cluster.

The development of the Gunsan national industrial cluster occurred during the 1970s and 1980s as a result of the growth of the automobile and shipbuilding industries. During the process of developing the heavy chemical industry, the economic structure was built with large corporations in which the government's intervention played a central role. The automobile industry of GM (established in 1994) and the Gunsan Shipyard of Hyundai Heavy Industries (established in 2007) have led the regional economy in and out of the cluster. However, the situation worsened with the shutdown of Hyundai Heavy Industries in 2017 and the closure of the GM plant in Gunsan. Subsequently, the companies that depended on these two large companies closed as well. Since then, employment, production, and exports have continuously declined throughout the cluster and the surrounding region, accelerating the decline of the city as a whole (Fig. 5). Currently, the Gunsan cluster is all hollowed out. There are vacant commercial and residential buildings and empty streets with "for sale" signs hung everywhere. Although the cluster attempted to shift its primary industry to others, such as the solar energy sector, it had trouble growing in such a short time because this radical structural change required a significant transformation from the previous system and political reliability from the residents.

Meanwhile, the Okpo, Jukdo, and Jinhae clusters in Gyeongnam flourished until 2007, but they followed a similar path as Gunsan. They were unable to overcome the crises they had faced over the years, including the global economic downturn, oil price decrease, and their industry's downturn, so they continued to stagnate. Samsung Heavy Industries also suffered a deficit due to its accumulated failures, the STX Group was dismantled, and Hyundai Heavy Industries and Daewoo Shipbuilding started cutting back on their operations. Due to the repeated problems caused by the industry's downturn, production volume decreased, office workers and engineers resigned, and young employees left for other jobs. The population fell more sharply as foreigners' and workers' families left along with the workers. This also resulted in a significant drop in enrollees in nearby schools. Furthermore, the industry's related majors, such as naval architecture and oceanography, also showed reduced numbers in 2016, with eight out of 46 students transferring to other majors.

5 Conclusion and limitations

Clusters facing a crisis could have devastating effects on the economic conditions of the regions where they are located. Thus, it is very important to find ways to sustain their success. This research quantitatively classified the life paths of different clusters and analyzed the determinants of resilience that were present when a crisis occurred. By classifying the types of life paths and resilience, we can easily comprehend the trends of clusters' growth and decline.

This classification made it possible to scientifically derive crisis-survivable clusters and to analyze the merits of such clusters. They were classified into three types: Malmo-type, Silicon Valley-type, and Detroit-type. Each type differs considerably from the others in that the Malmo-type and Silicon Valley-type have high resilience, whereas the Detroit-type has low resilience. The types with high resilience made good use of the determinants formed during their lifetime, but the type with low resilience could not make good use of such determinants, making it susceptible to crises.

To promote sustainable development, growth, and operation for clusters experiencing industrial crises, four determinants of resilience must be considered: multi-tiered industrial structure, human capital, government support, and location. When these four determinants come together in harmony, they strengthen a cluster's resilience in the process. Thus, these determinants must be monitored throughout a cluster's lifetime, either by the clusters themselves or by the government. This would help declining clusters get back on track within the short term after experiencing shocks. Otherwise, neglecting even one determinant can lead to a decline, as proven by the cases with the Detroit-type of path.

Each type has a key determinant of resilience that sets it apart from the others. The Malmo-type primarily employs industrial restructuring to overcome a crisis. G-valley, for example, transitioned from old traditional industry to IT and software, allowing them to grow again. The Silicon valley-type mainly relies on human capital. INNOPOLIS Daedeok, for instance, after establishing a strong network, continues to assist one another in remaining strong. The Detroit-type has been severely harmed by poor use of resilience as a single industrial structure. Gunsan, for example, was unable to recover from a series of failures.

This study also has limitations that must be considered. First, the similarities between the time-series graphs could be measured in a more sophisticated way using a different method. The shapes of the time-series data are very complex, so the DTW method may be unable to capture all the complexities of these patterns. However, the problem with using more sophisticated methods would be classifying the data into more than three groups. If there were many groups, it would be difficult to derive their common characteristics. Therefore, this study grouped them into just three types. In addition, a future study can conduct quantitative analyses on the correlation between the impacts of a crisis and the determinants of resilience. This analysis will help researchers evaluate which kinds of resilience work in a more supportive way. Also, a future study can compare the differences between Korean and non-Korean industrial clusters in order to identify a path that was distinct from the Anglo-American context.

Although this research used South Korean data as representative data for classification, the same classification method can be applied to the data of other countries. Through this classification, the necessary or weak determinants of resilience in their clusters can be found. By making up for these shortcomings, continuous growth can be achieved.

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