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A Study on the Numerical Approach for Industrial Life Cycle: Empirical Evidence from Korea

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Abstract

The industrial life cycle theory was extended to the product life cycle theory and the corporate life cycle theory, but a conceptual life cycle was presented, and quantitative empirical evidence for this was insufficient. It is intended to improve appropriate resource planning and resource allocation by quantitatively predicting the industrial cycle and its position (age) in the cycle. Human resources, tangible assets, and industrial output analysis were conducted based on 28 years of actual data of 39 industries in Korea by applying the Gompertz model, which is a population ecology prediction model. By predicting with the Gompertz model, the coefficient of determination R^2 value was 97% or more, confirming the high suitability with the actual cumulative sales value of the industry. A numerical model for calculating the life cycle of each industry, calculating the saturation of input resources for each industry, and diagnosing the financial stability of the industry was presented. These results will contribute to the decision-making of industrial policy officers for budget planning appropriately for each stage of industry development. Future research will apply the numerical model of this study to foreign national industries, complete an inter-industry convergence diagnostic model (e.g. ease of convergence, suitability of convergence, etc.) for renewal of fading industries.

Keywords: Industrial Life Cycle, Product Life Cycle, Corporate Life Cycle, Gompertz Model, Convergence Diagnosis

JEL Classification Code: C53, D15, L60

1. Introduction

Just as humans try to live a healthy life regardless of external influences, companies are also trying to adapt to the external business environment and generate continuous profits. Therefore, many scholars are actively studying corporate life expectancy. Just as the theory of systems based on biology applies to humans, enterprises also have the ability to preserve and maintain their organizations because they have organic characteristics. Just as companies want to make contributions to society by developing their own abilities as long as human life expectancy increases, they are also trying to create a positive cycle in which continuous employment and generated profits are returned to the community and the government in the form of taxes. Based on the product life cycle and the corporate life cycle, the industrial life cycle provides a framework for preparing step-by-step crises and countermeasures by allowing the creation of an industry, which forms a market, grows, and develops, and declines, and to identify the current location of the industry.

The concept of product life cycle is a process in which a product is first introduced to the market and then disappears from the market. This can be divided into the process of introduction, growth, maturity, and decline. After being first introduced by Levitt (1965), the concept of a product's life cycle used to describe the development of products, markets, enterprises, and industries presents a marketing strategy based on one product, which is the industrial life cycle theory that extends this logic to the industry. The industrial life cycle theory is divided into stages considering the evolutionary process of the industry and provides important

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implications for explaining the impact between industry and business as it can provide various interpretations such as structure of industry, development and prediction of industry based on the industrial characteristics of each stage. The theory of industrial life cycle suggests that industries and products are at a certain stage of their life cycle, depending on the change in sales and revenue. The duration of each phase may be short or long, depending on specific industries, as the path or characteristics of each phase are affected by a variety of market conditions such as technological development, market demand, competitive structures, and corporate factors.

Previous studies have only presented conceptual research analysis results through product life cycle and corporate life cycle theory, but this study has practically measured industrial life and age and diagnosed relative positions of specific industry. In addition, we have identified common patterns of input resources in the process of industrial growth and analyzed saturation by actual resources to demonstrate the necessity of fostering new industries, and we are going to present a numerical model that diagnoses financial stability of the industry and predicts the timing of risks.

As Korea has the highest research and development (R&D) investment per GDP, the export share of high-tech industries and patent registration per GDP, Korea's various industrial development cases have evolved from developing countries to developed countries. These can help other developing countries benchmark the policy direction of economic development as well as provide policy implications for the order and allocation of resources by industry.

This study attempts to present a model that can predict the life cycle of an industry, in a quantitative manner by estimating the sales volume of an industry by utilizing the Gompertz model, which predicts population life under the assumption that a company or industry also has finite resources and has a life cycle like a living organism. The Gompertz model is intended to contribute to the development of decision-making methodologies for the planning of corporate managers' human resource and asset investment or the allocation of policy budgets by quantitatively measuring the life cycle of an industry that is absolute, not a relative life cycle, and by measuring the saturation of human resources and tangible assets.

2. Theoretical Background and Literature Review

2.1. Theoretical Background

Under the theory of system and complexity, we intend to expand our research on the life cycle of human beings from organism to business by studying product life cycle, corporate life cycle, and industrial life cycle.

2.1.1. Analogy Between Organism and Economy

The view that accounts for a human organization as a single organism is called system theory. The theory is based on biology and has already been widely introduced in the study of organizational characteristics as an approach to interpret and analyze concepts such as constancy, gene, cell theory, evolution, etc. which are the main concepts of biology. These studies provide a more realistic understanding of how human organizations work and provide new implications for human organization research. An entity is a social entity that enjoys revenue by manufacturing and supplying products and services. It can be recognized as an organism with a life cycle that continues to grow and die. In addition, a complex system theory focused on the interaction of economic components was introduced and some of these theories were intended to complement the interpretation of industrial growth.

As previous case studies on importance of interaction among economic components in terms of mutual growth, Mengmeng (2018) described that economic environment is an important prerequisite for sustainable development. In harmonization with features of specific economic environment, economic players will generate innovative pattern of industrial achievement and create a win-win economic development. Jang et al. (2019) postulated that interaction among economic players, like open innovation, could be an effective strategic option for each other as a solution for acquiring resources for overcoming disadvantages.

The theory of self-organization refers to the structure of a system that builds itself in innovative ways without pressure from outside. When fungi are undernourished, they signal each other, and when tens of thousands of them start shaking in unison, gather in one place and reach a certain level, they form a cohesive mass, crawl and nourish themselves. Afterwards, when the environment improves again, they scatter and return to being single-celled organisms. Economist Hirschleifer (1978) described similarities in competing behavior in biology and economic systems. Ecologists Rapport and Turner (1977) described in detail the consumer behavior and production analogy of natural communities. These authors emphasized the nature of the similarity between ecology and economics. Peltoniemi (2005) considered that the concept and operating principles of natural ecosystems are complex adaptive systems, which have similar characteristics to business ecosystems in human society and conducted a study of analogies based on mutual similarities.

2.1.2. The Need for Complexity Theory

As the behaviors and aspects of various communities and their personal lives, including citizens and social organizations, as well as national states, are diversified and complex in each area of politics, economic, society and culture, attempts to interpret this phenomenon as a complex system are increasing. Complexity theory is incomprehensible with a Newtonian paradigm based on linear causality, and a theoretical alternative is required to describe a world interconnected with complexity.

2.1.3. Basic Concepts and Detailed Theory

The complexity theory, which evolved from system theory and chaos theory to interdisciplinary research, is based on systems thinking. As Bertalanffy (1968), a system is "an interrelated set of elements "which means a unit of a group of interrelated components, such as the solar system, the animal system, etc. It is believed that product cycle theory and corporate life cycle theory can develop into industrial life cycle theory. Every segment of the system, resembles the whole (Mandelbrot, 1988), and whichever part is cut, has full properties. The industrial life cycle can also be interpreted based on the theory of complex systems that interact with local resources, foreign competitors, domestic and foreign customers, and government support. In the end, the product, corporate and the industry, all have the same attributes.

2.2. Life Cycle Concepts and Literature Review

Life-cycle characteristics, which are highly predictable from birth to death and have repetitive steps and patterns, have the advantage of being able to clearly define the aging characteristics and mortality until death. Lippitt and Schmidt (1967), who first presented the concept of corporate life cycle, and Adizes (1986), who established the corporate life cycle, judged that if a company's life cycle was established based on the life cycle of these individuals, it could provide practical guidance that would make it easier and clearer to interpret the challenges faced by managers at each stage and to diagnose the possibility of corporate bankruptcy.

The concept of life cycle was formed on the basis of product stages according to growth rate and market share shown by Boston Consulting Group in the 1960s. Based on the growth rate, age, size, and performance, the company's life cycle is divided into three to five stages, including the introduction, growth, maturity, and decline, and each stage has a consistent characteristic. Levitt (1965) introduced the Industrial Life Cycle Theory for the first time as an extended concept in describing the concept of product life cycle as the development of product, corporate and industry. Just as the product life cycle is divided step by step and the industrial life cycle is interpreted and predicted, the industrial life cycle is also divided into the industrial phase-by-phase process and step-by-step characteristics and the development of the industry can be predicted in advance.

Peltoniemi (2011) focuses on interpreting the changing process of industries enjoying economies of scale as the type of production product decreases due to the development of technology and is used to explain the survival of enterprises in the industrial life cycle. Han (2016) argued that the relationship between industrial structure and technology startup performance had a significant positive effect on industrial growth rate, competition intensity, and barriers to entry, which was interpreted as a very important factor influencing technology startup performance. Zebua and Nasrudin (2016) identified the factors of GDP home country, GDP host country, real interest rate, distance and natural resources that determine the flow of direct investment between Asian countries. This confirmed that factors affecting the calculation of a country's industrial cycle are not only domestic but also foreign.

Wang et al. (2018) and others conducted a longitudinal study of Canadian telecommunications equipment manufacturing, with a study of the effects of spatial location on the creation of new ventures and the decline of enterprises over the industrial life cycle. They argued that as industries grow, the ability to create more new ventures increases when strong integrated externalities are close in other regions, but the ability to sustain existing ventures and create new ventures decreases in times of decline.

Li et al. (2018) said, "The basic concept of industrial life cycle theory originated from biology, which is linked to the life cycle of an organism". Depending on the industrial life cycle, all industries go through four different stages, each of which requires a strategy to effectively respond to a particular situation. The industry life cycle curves are shown in the form of S-shaped curves in revenue for the vertical axis and time for the horizontal axis. Usually, it is divided into four stages - introduction, growth, maturity, and decline. The analysis of the life cycle helps the corporate management control the business according to the situation of the industry.

Esteve-Pérez et al. (2018) surveyed 685 companies with more than 10 employees from 1993 to 2009 and studied their performance and productivity during the industrial life cycle as determinants of their survival through practical analysis in three stages of the industrial life cycle. In the early stages of the industrial life cycle, it was argued that the enterprise's performance is negatively correlated with its risk ratio, that both its performance and productivity play an important role in reducing its risk during the growth phase, and that in the mature stage, its performance does not play an important role in survival.

Piorkowska et al. (2019) presented the theoretical background and conceptual framework of dynamic relationships between enterprises according to the industrial life cycle as focus group interviews, longitudinal case studies and cross-sectional survey research methods. They observed that the strength of cooperation increases dynamically in the stage of industrial growth, and also in the phase of industrial decline, and that the intensity of competition increases in the stage of industrial growth and decreases in the phase of decline, and that cooperation between competing companies is important in the stage of industrial maturity and decline.

3. Research Method

The Gompertz curve was presented by Benjamin Gompertz (1779–1985), a British mathematician and insurance accountant, and described the population growth model. The Gompertz model is an S-shaped function that describes the slowest growth at the beginning and end of a particular period and is a type of time series mathematical model. Gompertz described population growth as a model, which can be assumed that population growth is also determined by limited resources and environment, and that industrial growth has a life span, such as people, animals, plants, markets, etc., and the behavior of industrial growth variables over life will show normal distribution.

The following general solution can be derived from the Gompertz model.

$$\frac{\mathrm{dP}}{\mathrm{dt}} = rP\ln\left(\frac{K}{P}\right) \tag{1}$$

where, P = Population
t = Time elapsed
K = Environmental receptive capacity
r = Positive constant

The solution is

$$P(t) = Ke^{ce^{-rt}} = Ke^{\ln\left(\frac{P_0}{K}\right)e^{-rt}} \tag{2}$$

$$P(t) = Ke^{\ln\left(\frac{P_0}{K}\right)e^{-rt}} = Ka^{b^t} \tag{3}$$

where, $e^{\ln\left(\frac{P_0}{K}\right)} = a, e^{-rt} = b^t$

According to previous studies, the Gompertz model is used in various ways, including forecasting product sales, forecasting growth and death of people or animals and plants, forecasting tourism demand, forecasting market potential, and forecasting movie demand. Therefore, the cumulative population $P(t)$ in the Gompertz model is changed to cumulative sales $Y(t)$ by deducing that population growth and sales growth will be similar and using sales as data for growth forecasts.

General Solution (3) can be obtained as below

$Y_t = K \cdot a^{b^t}$ and, applying the log function, in can be converted to

$$\log Y = \log K + (\log a) \cdot b^t \tag{4}$$

where, Y_t: Cumulative sales up to t period
b: Degree of obsolescence $0 < b < 1$
a: Initial market acceptance rate $0 < a < 1$
t: Years
K: Total Potential Market

From General solution $Y_t = K \cdot a^{b^t}$ It can be deployed over time as

$$Y_1 = K \cdot a^{b^1},\ Y_2 = K \cdot a^{b^2},\ Y_3 = K \cdot a^{b^3}$$

When applying log,

$$\log Y_1 = \log K + (\log a) \cdot b^1 \tag{5}$$

$$\log Y_2 = \log K + (\log a) \cdot b^2 \tag{6}$$

$$\log Y_3 = \log K + (\log a) \cdot b^3 \tag{7}$$

If above simultaneous equations are solved,

$$b^n = \frac{\sum_3 \log Y - \sum_2 \log Y}{\sum_2 \log Y - \sum_1 \log Y} \tag{8}$$

$$\log a = \left(\sum_2 \log Y - \sum_1 \log Y\right)\frac{b-1}{(b^n-1)^2} \tag{9}$$

$$\log K = \frac{1}{n}\left[\sum_1 \log Y - \left(\frac{b^n-1}{b-1}\right)\log a\right] \tag{10}$$

Gompertz and logistic models, commonly used in growth models, have something in common with the “S” shape. However logistic curves have symmetrical shapes left and right around inflection points, while Gompertz curves have asymmetrical features around inflection points. The Gompertz model was originally designed to explain human mortality. It is used in marketing to predict market growth for new mobile phones, or even to predict growth of bacteria, tumor cell growth, and disease spread in the agricultural and aquaculture sectors.

Tsai (2013) used an expanded Gompertz model with absolute price fluctuation value to forecast quarterly LCD TV shipments from Q1 to Q4 of 2009 and found that small LCD TVs had high market penetration while large LCD TV panels had low market penetration. Jha and Saha (2018) used the Bass, Gompertz and simple logistic growth models to analyze the diffusion from 2G to 4G in Germany, the UK, France, and Italy, the four major economies in Europe, and forecast the adoption of 3G, 4G and 5G mobile broadband. Taro (2018) showed that the growth of tumors can be predicted under the Gompertz cell growth model based on data that tracked 250 untreated breast cancer patients for 20 years. By applying this model to long-term breast cancer research, mammary tumor growth could be predicted as a function of time.

Zardin et al. (2019) used the Gompertz model to estimate the growth curve of a Brazilian fish named Nile Tilapiasia and examine the differences in gender growth. Olukayode (2019) applied the Gompertz function approach to solve the population growth problem in Nigeria, and developed the Numerical Scheme, which proved to be numerically stable and convergent. The numerical value of this method showed almost the same results as the general solution, and was effectively used to predict future population growth in Nigeria. Satoh and Matsumura (2019) found that the Gomperz and logistic models used for market acceptance forecasting, gradually converge to the estimated potential market size as the collected data size increases. It also demonstrated that when the data size approaches infinity, the size of the potential market converges to the estimated threshold with the Gompertz model.

Jha and Saha (2020) compared and evaluated using Bass, Norton-Bass, Gompertz and Logistic models in a study that predicts and analyzes the diffusion characteristics of India's 3G and 4G broadband mobile services. While Bass models are sensitive to both past 3G and 4G data, Gompertz and logistic models are well suited to the same data and predict that the 4G spread is 6.1 times faster than the 3G spread. As seen in the above, the Gompertz model is used in various predictions and forecasting.

The logistic model is more suitable when the past trend has a greater effect in the future, and the Gomperz model is more suitable when the current change has a greater effect than the past trend. Logistic models and Gompertz models can be easily estimated through linear regression analysis through variable transformation, so they are convenient to use, but the models are not intuitive and are difficult to interpret. The Gomperz model could explain better industrial growth than the Bass model, which has a large influence of imitators and is suitable for the spread of a single product, or a logistic model based on a symmetrical selection probability.

Similar to the animal life cycle, the growth of the industry goes through a period of birth, growth, maturity, and decline. Finally, the cumulative sales of the industry also goes through the life cycle of the industry that follows the Gompertz growth curve model, over time such that it develops naturally like population growth. Therefore, this study predicts the average growth of the industry based on the cumulative sales for 28 years within the industry, calculates the industrial cycle quantitatively according to the forecast curve of the average growth, and presents an evaluation method based on a more objective method. The research models of this study are as follows in Figure 1.

The Gompertz general solution (3)

$$Y_t = Ka^{b^t} \tag{3}$$

When time $t = 0$ in the equation,

$$Y_0 = Ka^{b^0} = Ka$$

Therefore, a = $\frac{Y_0}{K}$ can be obtained, where a is the initial market acceptance rate of Industrial sales. The derivative for time t is expressed as $a^{b^t} \ln(a) b^t \ln(b) K$, again, the derivative for time t for equation is $a^{b^t} \ln(a) b^t \ln^2(b)\left(\ln(a) b^t + 1\right) K$. The inflection point appears at time t when the above expression becomes 0, and it is expressed in terms of parameters a and b as follows

$$t = \frac{\ln\left(-\frac{1}{\ln(a)}\right)}{\ln(b)} \tag{11}$$

This means that the time t at which the inflection point appears becomes larger as the value of b increases, and as the value of b increases, the survival period of the industry is longer. If the value b has a smaller value, the survival period will be shorter, indicating that obsolescence will progress faster. In the Gompertz model, K stands for environmental adaptability, but in the industry's growth model, it stands for potential markets.

4. Analysis and Results

4.1. Industrial Cycle Calculation

The data extraction and processing methods used industry-specific sales, number of employees and time series data from 1991 to 2018 provided by the Korea Institute for Industrial Economics and Trade and predicted industrial cycles with the Gompertz model. To increase the accuracy of predictions for cumulative sales, the model fit was verified by calculating the variables K, a, and b for which root mean square error (RMSE) could be minimal, and by calculating the total sum of squares (SST) and sum of squared estimate of errors (SSE) to verify the accuracy of the predicted model.

For fine chemistry, the coefficient of determination $R^2 = 1 - \text{SSE/SST} = 0.996$ showed model fit of 99.6%, and for the rest of the industry, the table below shows model fit of at least 0.97.

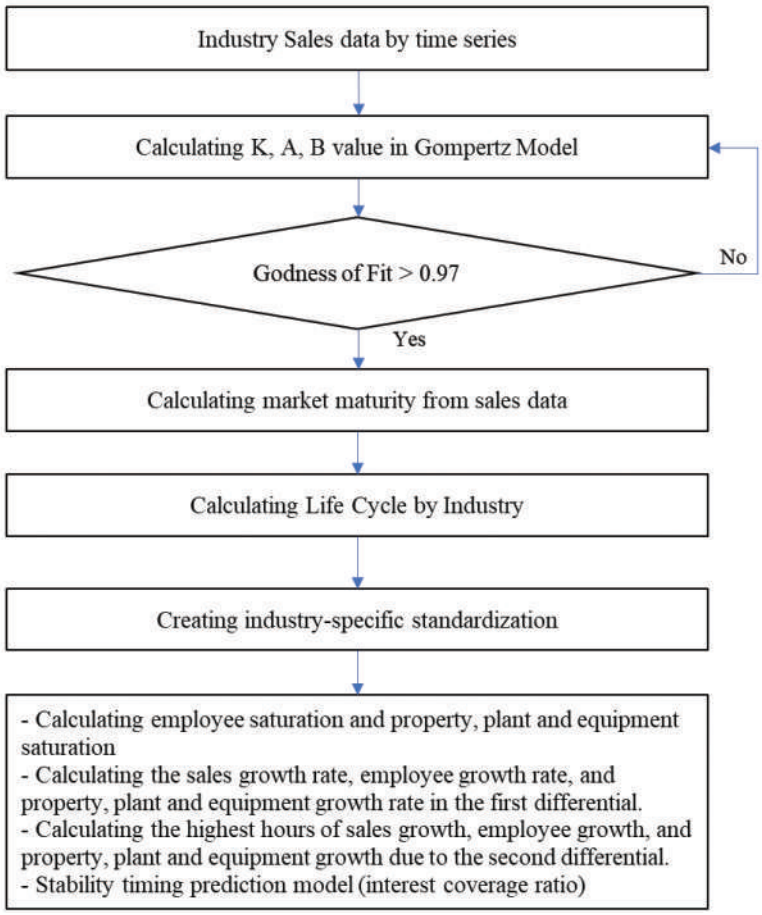

Figure 1: Research Model of this Study

The above (3) formula defines the cycle of industry as from 0.01% to 99% and calculates it by substituting it as follows:

$$0.99\,K = K \cdot a^{b^t} \tag{12}$$

$$0.0001\,K = K \cdot a^{b^t} \tag{13}$$

$$t = \log\left[\log(0.99)/\log(a)\right] / \log(b) \tag{14}$$

$$t = \log\left[\log(0.0001)/\log(a)\right] / \log(b) \tag{15}$$

The results of this study show that the average industrial life cycle is 92.6 years, and the standard deviation is 30.7 years, with a large spread of the inter-industry life cycle.

The battery industry's life cycle is 231.1 years, the longest among all industries, and the current potential market size is 1 ten quadrillion 3,867 trillion won. On the other hand, the shortest industrial life cycle is the computer industry, which has an industrial cycle of 36.2 years, and the potential market size is 229 trillion won, and 97.8% of the current market size is saturated. Taking the computer industry as an example, the industrial cycle is (14)–(15) = 36.2 years, and the market maturity can be expressed as the ratio of cumulative sales and market size (K), calculated as 224,135,313 / 229,239,718 = 97.8%.

4.2. Industrial Obsolescence and Market Maturity per Industrial Life Cycle

If the ratio of the market currently located in the entire potential market K is defined as market maturity, industry groups can display market maturity and obsolescence (b), as in Figure 3.

As Figure 3 shows, the size of the circle is the size of each industry's potential market, and the x-axis refers to the maturity of the current market versus the potential market, and the Y-axis refers to the obsolescence of the industry. It was analyzed that the computer industry is in a state of decline.

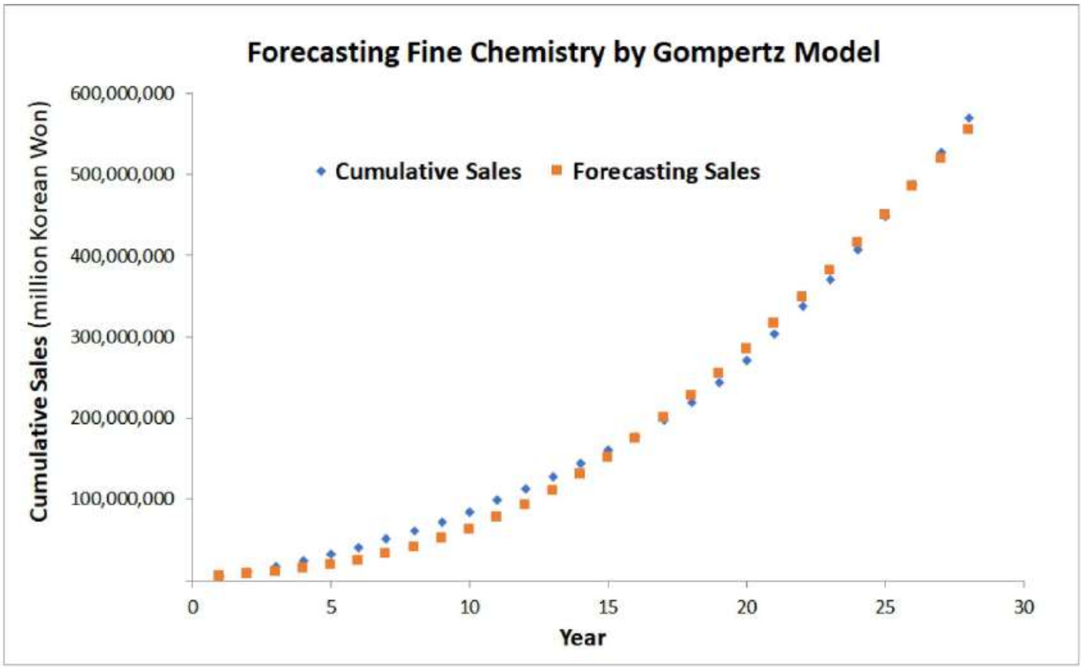

Figure 2: Gompertz Model Simulation and Accumulative Revenue Forecast for Fine Chemistry

Figure 3: Market Potential, Market Saturation Ratio per Obsolescence Rate (High and Mid High Technology)

This shows that the current method of classifying current technologies as high and low and that the analysis in this study is different. It can be concluded that for all industries, the less mature the market, the less is the obsolescence.

4.3. Standardized Location of each Industrial Categorization

OCED is a graph compiled by categorizing industries into high-level, mid-high, mid-low and low-level technology based on R&D intensity, while Figure 4 is regular distribution of saturation for each industry by sales. The high level of technology does not mean that sales saturation is low, indicating that classification by technology level and classification by sales is different.

4.4. Sequence of Resources

Figure 5 standardizes the number of employees, the tangible fixed assets, and the revenue, and resulting in an empirical result that the cumulative value of the employees of the intangible asset preceded, followed by the tangible fixed assets, and the resulting cumulative sales of those across the industry is ultimately followed. In most industries, tangible fixed assets precede sales, but in the shipbuilding industry, which is the ordering industry, sales are preceded, and tangible fixed assets are lagging behind.

This shows that in the human growth curve, the brain's growth curve precedes the body's growth curve (Bogin, 2020). This can be said to be the result of the input of human resources and assets preceding input of sales, in the case of business or industry.

According to this study, the saturation of employees in all industries, except for batteries, aviation, fine instruments, telecommunication devices and shipbuilding, was over 70%. This is an actual data showing that Korea's growth pattern in most industries since 2000 has been driven by jobless growth, suggesting that industries and policy authorities should create new growth engines for new industries or convergence industries.

4.5. Predicting the Financial Stability of an Industry

Based on the results of this study, the time when the growth rate of sales, employees, and tangible fixed assets produced by the primary differential function is the highest can be calculated by equation (11), and Figure 6 shows the growth rate of employee growth, tangible fixed assets, and sales growth by year using the formula obtained from the Gompertz model.

At this time, the interest coverage ratio in each industry is estimated to have plummeted around the peak of employee growth, as the growth rate of tangible fixed assets and the

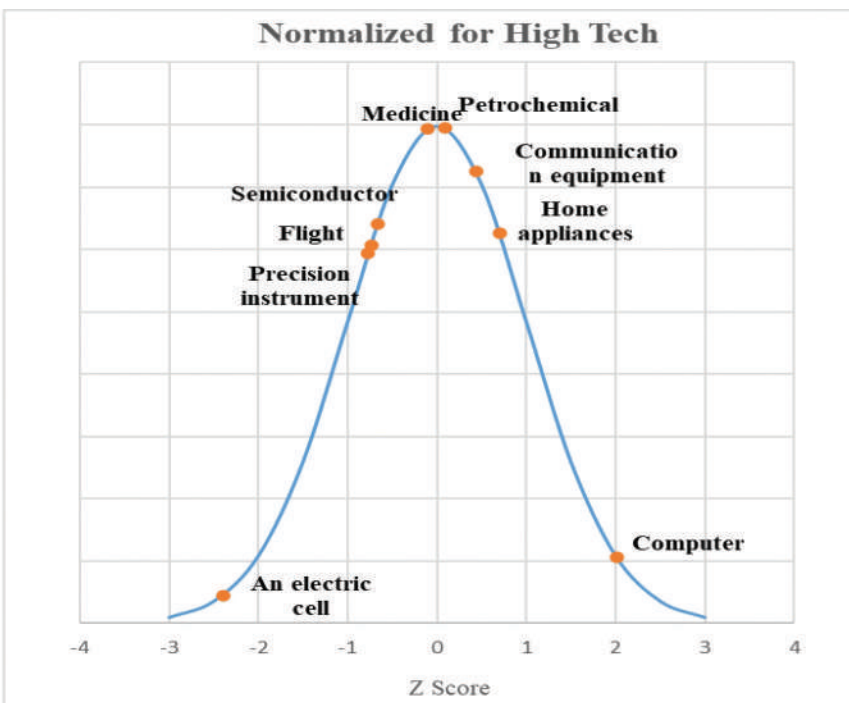

Figure 4: Industrial Life Cycle (Normalized for High Tech)

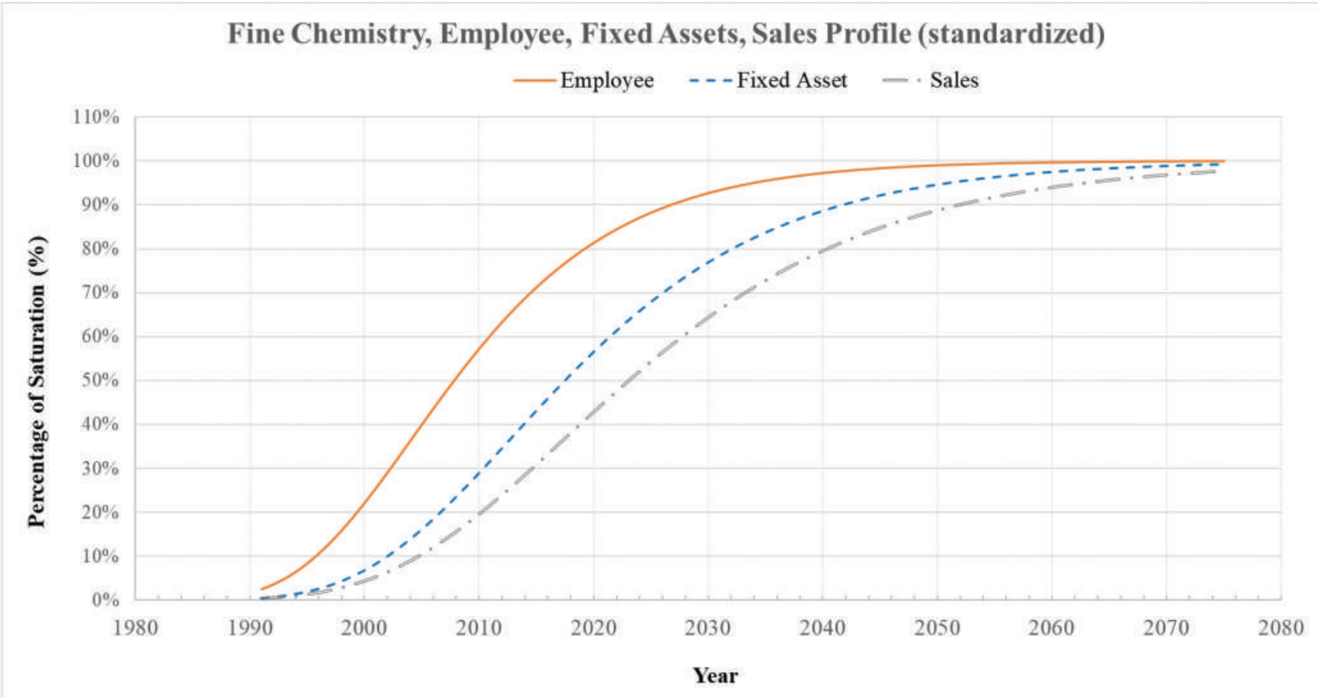

Figure 5: Fine Chemical Industrial Life Cycle (Normalized for Mid Low Tech)

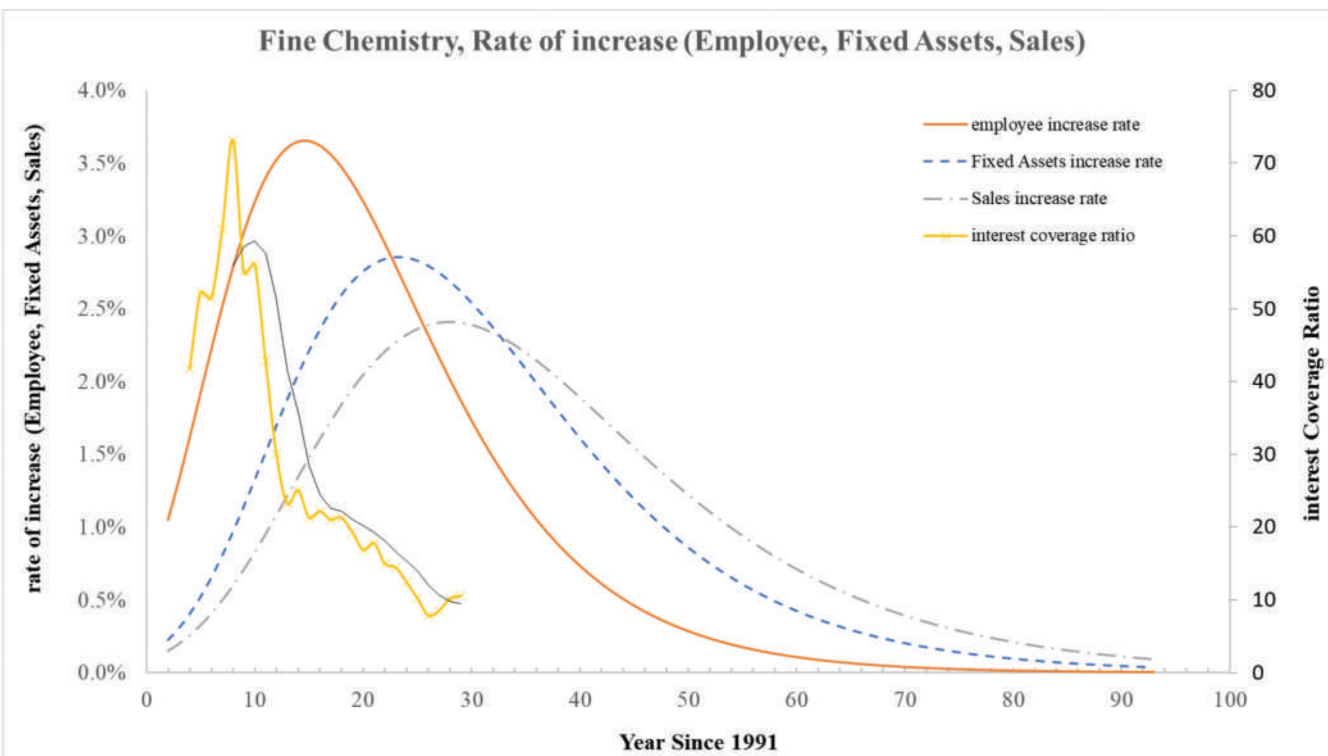

Figure 6: Employee, Fixed Asset and Sales Increase Rate per Year

increase in sales increases, and the maximum input and the lowest performance around the peak of employee growth rates are believed to have led to a sharp drop in interest coverage ratios.

For example, for fine chemistry, the highest year of employee growth is calculated as t = 14.1 years, t = 22.75 years of tangible fixed assets, and t = 27.49 years of growth in sales.

The correlation and regression formula between employee growth rates and interest coverage ratios in each industry are obtained. The correlation between the two variables is positive at 0.75.

The time when the interest coverage ratio drops below a significance level of 1% is positively correlated with the peak of the employee increase rate. One-unit increase in the peak of the employee increases interest coverage ratio drops by 0.49 units. This could give industry policymakers implications for measuring industry stability as a function of employee growth curves. If this is expanded to fractal theory, it is believed that the company's crisis will be predictable in advance by using the curve function of employee growth.

5. Conclusion

The Gompertz model is a methodology with high reliability in predicting dynamic (time series) saturation of industry. In addition, information on potential market size (K) and diagnosis of obsolescence (b) can be obtained simultaneously. In fact, when the cumulative sales of the fine chemical industry were predicted by the Gompertz model, the coefficient of determination R^2 was 99.6% or higher, confirming the cumulative sales measure and high fitness of the industry. In other words, the industrial saturation through the Gompertz model matched the life span of the industry to confirm that diagnosis was possible.

With the Gompertz model, the cumulative sales saturation of the industry is set at 0.01% and 0.99% as the entire industrial life cycle, which can be quantitatively calculated, and the current cumulative sales saturation can be interpreted as the current age of the industry. The analysis showed that the average industrial life cycle for all industries was 92.6 years and the standard deviation was 30.7 years. The battery's industrial life cycle is 231.1 years, the longest among all industries, with the largest potential market size of 1 ten quadrillion 3,867 trillion won. While the shortest industrial life cycle is the computer industry with 36.2 years of industrial life cycle.

In addition, the current age (accumulated sales saturation) by industry was normalized and then mapped to identify the standardized relative position of industry age under the life cycle. The analysis showed that the industry with higher technology levels was not relatively low in age. This demonstrated that the OCED in 2016 was different from the life of the real industry by the OECD classification criteria (high, medium, low, and low technology groups) based on R&D intensity.

When the life and age of an industry were analyzed through the analysis of sales saturation, the pattern of resources invested in the process of industrial growth was analyzed through the analysis of input resource saturation by industry. As a result, excluding some special industries (e.g. shipbuilding, etc.) the saturation of employees of intangible assets was preceded by saturation of CAPEX investment of tangible assets, and a grand pattern was derived for the order in which sales were saturated. In addition, among the 39 industrial groups in Korea, more than 70 percent of employees are saturated except for four other industrial groups, suggesting the need to foster new convergence industries.

Finally, in order to present a model for predicting the timing of financial stability risks in industrial growth, the pattern of interest coverage ratios, a representative indicator of financial safety, was compared with input resources and revenue growth rates, and correlation analyses confirmed that there was a positive correlation between employee growth rates and interest coverage ratios in each industry.

Previous studies for industrial life cycle such as Peltoniemi (2011), Li et al. (2018), Stanczyk-Hugiet et al. (2019) have only presented conceptual research analysis results but this study has practically measured industrial life and age and diagnosed relative positions of specific industry as a numerical model. In addition, we have identified common patterns of input resources and diagnosed resource saturation and financial stability in the process of industrial growth.

Differences in structure changes according to the stage of development of industries are reflected in industrial policies, policy-wise and strategic implications can be given to industrial development policies for growth in the early stages, to create a free competitive environment for each other in the early stages of growth, and to find new growth engines through convergence of heterogeneous industries or intermittent technological innovation in the mature stage. This study calculated the industrial cycle by using the time series sales data by industry and the Gompertz model, and quantitatively presented where each industry is currently located.

This research is based on the industrial database of the Korea Institute for Industrial Economics and Trade, and there is a limit to presenting it as a result of a study that covers the characteristics of each country's industries. Future studies would like to apply the numerical interpretation model of this study to foreign national industries in order to quantitatively interpret the life and age of those industries, input resource patterns and industrial financial stability. In addition, the company will complete a model of convergence diagnosis (ease of convergence, compatibility of convergence, etc.)

for the replacement or conversion of fading industries into convergence industries.

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