Possibility of Chaotic Motion in the R&D Activities in Korea

Jeunghwee Loh

Abstract

In this study, various characteristics of R&D related economic variables were studied to analyze complexity of science and technology activities in Korea, as reliance of R&D activities of the private sector is growing by the day. In comparison to other countries, this means that it is likely to be fluctuated by economic conditions. This complexity characteristic signifies that the result of science and technology activities can be greatly different from the anticipated results - depending on the influences from economic conditions and the results of science and technology activities which may be unpredictable. After reviewing the results of 17 variables related to science and technology characteristics of complex systems intended for time-series data - in the total R&D expenditure, and private R&D expenditure, numbers of SCI papers, the existence of chaotic characteristics were. using Lyapunov Exponent, Hurst Exponent, BDS test. This result reveals science and technology activity of the three most important components in Korea which are; heavy dependence on initial condition, the long term memory of time series, and non-linear structure. As stable R&D investment and result are needed in order to maintain steady development of Korea economy, the R&D structure should be less influenced by business cycles and more effective technology development policy for improving human resource development must be set in motion. And to minimize the risk of new technology, the construction of sophisticated technology forecasting system should take into account, for development of R&D system.

Keywords : Science and technology Activities, Chaotic System, Sensitive Dependence on Initial Condition, Long Memory of External Shock, Non-Linearity, and Complexity

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* Lecturer at Dept. of Economics, Mokpo National University, e-mail : jhloh00@hotmail.com

1. Introduction

In this study, from examining input and output elements such as R&D expenditure and growth in the number of researchers, evidences will determine whether chaotic characteristics of R&D activities are present, and if they are present, they will be studied and the resulting policy implications will be reviewed after.

In input terms of the current state of the science and technology activities, R&D expenditure and personnel are showing a continuous growth. In particular, in the case of R&D expenditure in relation with the proportion of GDP appears to be world-class. According to Ministry of Science, ICT and Future Planning, Korea's Total R&D Expenditure in 2012 was 5,559.7 billion USD which has increased 11.1% from the previous year and, R&D expenditure/GDP ratio was 4.36%, making Korea as the world's second largest ratio, following Israel. The private sector in the total R&D expenditure was 77.9%, which means that Korean R&D expenditure is mainly led by the private sector. And Number of Researchers per thousand- labor force in Korea is 12.4 persons which show higher than 10.0 peoples in Japan, 9.1 persons in the United States, 8.5 persons in France, 8.3 persons in the UK and other major developed countries [Ministry of Science, ICT and Future Planning, 2013].

In output terms of science and technology activities, according to applications in 2012, intellectual property recorded 396,379 cases in 2012, increased by 6.8% from the previous year and patent applications were 188,305 cases in 2012 - world's fourth highest record. The numbers of IPC in 1 patent, increased from 1.08 cases in 2000 to 2.5 cases in 2011 shows that increase of the advancement of technology convergence and complexity was on course [Korean Intellectual Property Office, 2013]. Also looking at the number of papers published in Universities on national and international journals, it recorded 7.15% increase with 66.745 papers from Universities during year 2011, and from two-year colleges, 14.6% increase with 2,114 papers in the same year. The proportion of international professional journals among those papers was steadily increased by 36.4% and 7.0% each respectively. Especially, as the number of papers looking at per capita, the interdisciplinary research such as library and information science, brain science, and science and technology studies, showed highest increase by 1.13 papers [National Research Foundation of Korea, 2013].

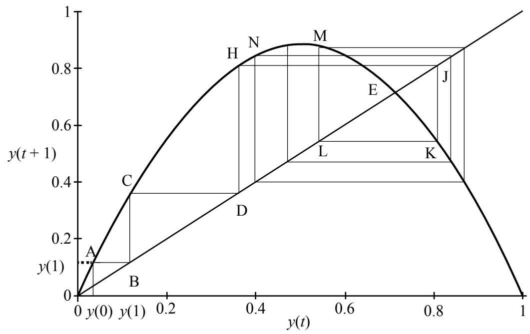
To sum up, the characteristics of the science and technology activity in Korea depend highly on private sector which is sensitive to economic situation. And in output, both in terms of patents and papers, various technologies' interdisciplinary advances are in progress.

If the chaotic characteristics exist in science and technology activities, this raises two critical points to review. First, if the chaos characteristics exist in the systems, due to its sensitive dependence on initial condition, even small changes in external conditions may significantly change results from the expected events. Because, as Rhee pointed out, having the chaotic characteristics in science and technological activities suggests that market failure, such as bubble burst and crisis, can cause relatively larger economic loss [Rhee, 2006]. Secondly, it means that the delicate planning of science and technological activities will be needed as well as more considerate approach on reviews of schemes.

2. Theoretical Background

According to Kim [2003], in contrast to the traditional paradigm which favors the equilibrium, 7 properties of chaos or complexity systems are as follows; First is 'Disequilibrium' which means that it can be changed by even a minor fluctuation due to its open system which reciprocally exchanges the external environment and material or energy, and information consist of sub-systems that are constantly aligning and conflicting. Second system contrasts to mechanistic determinism which sets linearity as a promise; 'Non-linearity' that raises a need for reviewing complexity of a system, thereby acknowledging the difficulty within identifying causality for linearity in reality. Third is 'Dissipative Structure' that is "far from equilibrium, it not only maintains itself in a stable state but also may evolve", which can be interpreted as the result of non-linearity structure determined by bifurcation accompanied by process of probability. Fourth is 'Self-Organization'; the formation of a spontaneous orders. Fifth is 'Fractal Geometry' – when parts are enlarged, multi-layered infrastructure – recurring of same structure – exists within. Sixth is 'Autopoiesis', the systematic self-referential process based on the principle of in the life cycle. Seventh is 'Coevolution', evolving phenomenon accompanied with destructive impact of interdependent elements. These characteristics can be summarized as, "A phenomenon that shows complex and irregular stochastic behavior though certain deterministic system is changing according to the rules" [Kim, 2003].

The efforts to find these characteristics of Complexity or Chaos System in economic variables have been in progress. According to Baumol and Benhabib [1989], the dynamics of chaotic system in economy has been progressing steadily to explain fluctuations, and its prime example can be the economic model based on different equation by Samuelson [1939]. From Baumol and Benhabib [1989]'s argument, the complex systems theory explains deterministic, but as for non-linear movement of variables, it is possible to infer that extremely complicated series of path can be created by relatively simple non-linear differential equations.



〈Figure 1〉 Coexistence of Convergence and Divergence in Time Path of y_t [Baumol and Benhabib, 1989]

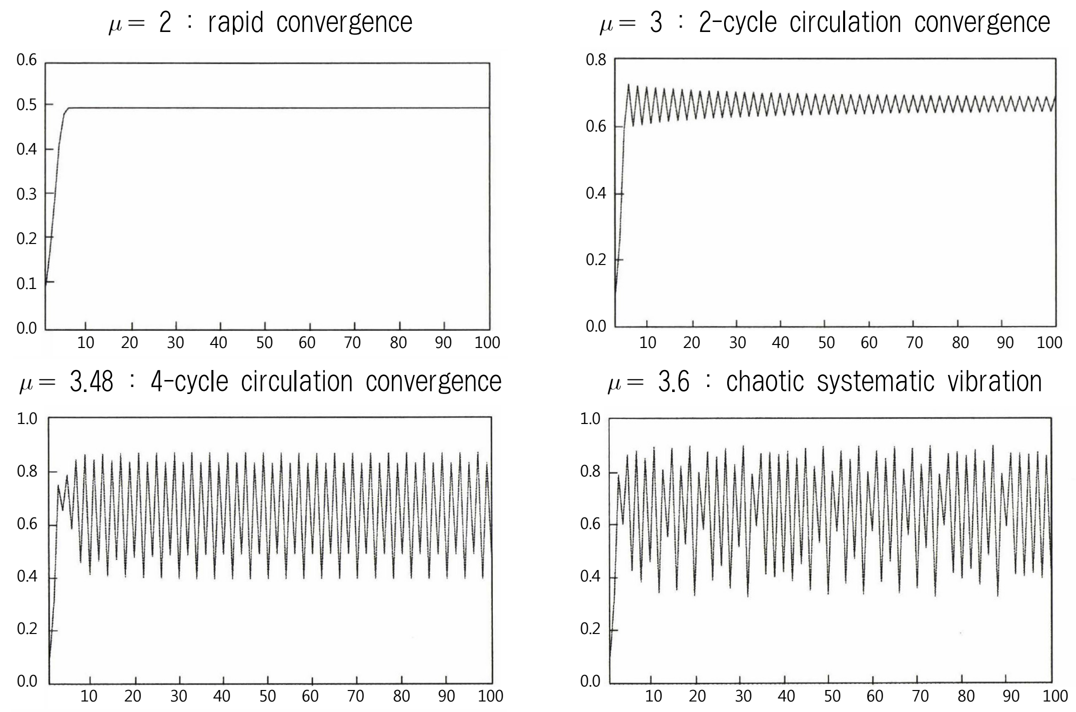
In addition, these characteristics of chaotic system can cause different results even by a very small numerical error, making it difficult to predict results. Therefore chaotic characteristics are not the only factors that make it difficult to predict economy but also are very crucial factors to reconsider when evaluating the effectiveness of policies – as the result of external shock such as government policy can have far greater impact than predicted. The below model is to describe the movement of the chaotic system in economic model using only simple first order differential equation using one parameter μ.

$$y_{t+1} = f(y_t) = \mu y_t (1 - y_t)$$

where, $dy_{t+1}/dy_t = \mu(1-2y_t)$

As illustrated in <Figure 1>, Phase Diagram can be obtained based on this model. The phase diagram represents changes of relation between y_t and y_{t+r}. Here, 45° line acts as a feedback system. Especially without any external impact, the left and right side of point H, and the movement of y became different from each other. According to Baumol and Benhabib [1989] and Jo and Rhee [2002], these movements can be classified into four types; non-existence of feedback process depending on the value of μ, rapid convergence due to equilibrium of steady state, slow convergence due to equilibrium of steady state, and showing circulation of over two cycles of converging or chaotic system [Baumol, 1989].

According to the <Figure 2>, looking at the path of the logistic function's value y_t following the change in parameter μ, parameter $\mu = 2$ shows rapid convergence, while parameter $\mu = 3$ shows circulation of 2-cycle with visible vibration. When $\mu = 3.48$, it shows pattern of



〈Figure 2〉 Four Movement Types of Time Paths Varying μ

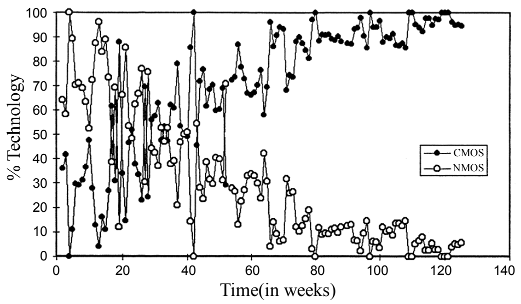
circulation of 4-cycle, complex data is calculated as μ gets closer to 4, and when $\mu = 3.6$, the t+1 forms chaotic systematic pattern as it becomes difficult to predict its value [Jo and Rhee, 2002].

Discussion of these complex systems have been carried out mainly on two different approaches. In terms of mathematics, it explores whether the strange attractor exists in the non-linear dynamic system, and from the economics' or statistics' point of view, it identifies whether non-linear dynamics are in given time-series of data [Huh and Suh, 2000].

From these points of view, study of chaotic system based on collected data has been progressed to determine whether non-linear dynamic system exists in time-series data. In particular, the study has been conducted mainly with financial data such as stock index and exchange rate to determine the existence of chaotic system in economic system - as it needs data that is generated in large quantities, during relatively short period of time. According to Sewell [2008], since Savit introduced research of chaotic system to the financial market in 1988, many studies have been made, and among empirical papers that examined the possibility of existence of chaotic system in financial market. Peters [1991] argued that possible existence of chaotic system in the financial market and Blank [1991] shows S&P 500 stock index and futures price of soybean crops are inherent system with chaotic characteristics [Sewell, 2008]. On the other hand, Decoster, Labys, and Mitchell [1992] asserted that there was a non-linear structure in the futures prices of copper, silver, sugar, and coffee, Wei and Leuthold [1998] also showed there was the process of chaotic system in futures price of corn, soybeans, wheat, pork, and coffee. And Panas and Ninni [2000] also found evidence of chaotic system in crude oil prices that was traded on the Rotterdam and Mediterranean crude oil market, while Antoniou and Vorlow [2005] found non-linear characteristics based on the FTSE 100 stock price-earnings ratio data.

Among domestic study of chaotic system based on the financial and macroeconomic data, as well as Huh and Suh [2000], there are Baek [1997], who analyzed the chaotic structure in stock indexes of classified domestic industry, Rhee [1998], who determined phenomenon of chaotic structure in price formation mechanism in the capital market [23], Chang and Kim [2004], who examined the possible existence of chaotic system in prediction of house market prices, and Kim [2007], who introduced forecast methodology of artificial neural network under the assumption of chaotic system existence.

On the other hand, research has been conducted on the possibility of the presence of chaotic system in science and technology activities related to the topic of this study. These researches have been conducted mainly to debate whether science and technology or R&D activity can create chaotic system. Baumol and Wolff [1992] noted, that the growth was made in the R&D in investment and manpower - while productivity declined in the U.S., and proposed the possibility of chaotic system that can be caused by imbalance between R&D, meaning production and dissemination, and velocity of R&D activities among inter-industry exist as mathematical model [Baumol and Wolff, 1992]. And Kopel [1996] presented the possibility of chaotic system in R&D activities by applying anchoring and adjustment heuristic decision and combining sales data which applied arc-tangent function with R&D expenditure functions [13]. Also, Jayanthi and Sinha [1998], who examined the possible existence of chaotic system based on the data generated from innovation activities in semiconductor industry, revealed the attributes of chaotic system exist - as shown below - by analyzing semiconductor wafer fabrication time, and the change of assembly time in yield ratio between 125 weeks in semiconductor manufacturing process where NMOS changes to CMOS.



〈Figure 3〉 Semiconductor Manufacturing Process where NMOS Changes to CMOS [Jayanthi and Sinha, 1998]

3. Methodology and Data

Various methods have been applied to reveal the presence or absence of chaotic characteristics in economic time series data. Jo and Rhee [2002] presented R/S Statistics to reveal the characteristics of long-term memory, BDS test to identify the linearity properties, and calculating Lyapunov Exponent as a method to examine whether chaotic characteristics exist in certain time series. Huh and Suh [2000] present Hurst Exponent, configuration of the virtual topological space, calculating the fractal dimension, and Lyapunov Exponent as their choice of methods. On the other hand, Jayanthi and Sinha [1998] present shuffle test, estimation of the correlation dimension and calculation of Lyapunov Exponent as another method.

Synthesizing with these methodologies, this study calculates Lyapunov Exponent to determine Sensitive dependence on initial condition that is the flagship characteristic of determining existence of chaotic system. And calculate Hurst Exponent to determine whether there is a long lasting impact, and conduct BDS test to judge whether time series data have a non-linear structure.

3.1 Lyapunov Exponent: Sensitive Dependence on Initial Condition

Lyapunov Exponent is a hallmark for measuring sensitive dependence on initial condition (SDIC) which is the representative feature of chaotic systems. Lyapunov Exponent measures how fast the closed trajectories break away in their topological space. There is one Lyapunov Exponent in each dimension of the topological space and when Lyapunov Exponent's value is positive, it is interpreted as a divergence, when its value is negative, it is interpreted as convergence. For example, such as $x_{t+1} = f(x_t)$, a one-dimensional non-linear function into account, after certain time elapses, two adjacent points x_0 and $x_{0+\delta}$ with very little difference δ makes trajectory, then the difference of trajectory d_n may be defined as follows.

$$d_n = e^{\lambda n}\delta$$

Changing above equation to log formation and summarizing into λ, following equation can be derived

$$\lambda = \frac{1}{n} log \left|\frac{d_n}{\delta}\right|$$

Where, d_n = The distance between two trajectories after certain time (n)
δ = Slight initial difference,
λ = The divergence rate of the trajectory or Lyapunov Exponent

Lyapunov Exponent, represented as λ, denotes exponential release of two locus with slight initial difference which means that the difference between initial conditions is enlarged according to time elapsed. Thus, λ with a value of + signifies that predictability is restricted as such, which is the key feature of chaotic dynamics [Rosenstein et al., 1992; Baek, 1997; Jo and Rhee, 2002; Min and Kim, 2006; Übeyli and Güler, 2007].

3.2 Hurst Exponent : Long-term Memory of Time Series

The Hurst Exponent can judge how long the effect of external shocks last; It is based on Hurst's research on exponent for water volume of the Nile River in Egypt. In order to determine the presence of Hurst Exponent, R/S analysis will be used. Declaring total sample number as T, its time series as X, and X's sub-sample as N, it is possible to express N's accumulated deviation as following equation [Hurst, 1965].

$$X_N = \Sigma_{T=1}^{N}(e_i - M_N)$$

Where, X_N = the cumulative deviation of sub-sample N,
e_i = date on a period i,
M_N = mean of data during period N

This cumulated deviation X_N presents as much as numbers of T/N in total sample T, and the range of cumulative deviation can be defined as the difference between the maximum and minimum values of the cumulative deviation.

$$R = Max(X_N) - Min(X_N)$$

Where, R = the range of cumulative deviation,
$Max(X_N)$ = the maximum value of X_N,
$Min(X_N)$ = the minimum value of X_N

Because the value of R may vary according to the size of the sub-sample, the general normalization procedure to apply the R/S (Standardized R) may be switched as following process which was obtained through Hurst's long-term observation of the level of Nile River in Egypt.

$$R/S = (a \times k)^H \rightarrow \left(\frac{N}{2}\right)^H, \ H = \frac{\log\left(\frac{R}{S}\right)}{\log\left(\frac{T}{2}\right)}$$

Where, R/S = Rescaled Range,
k= Numbers of Subsample(T/N),
a = Specific Constants,
H = Hurst Exponent

On the other hand, Mandelbrot [1969] proposed, through a regression analysis of the Hurst Exponent calculation method, as the following.

$$Log(R/S) = \log(a) + H(\log(N))$$

Where, R/S = Rescaled Range,
N = size of Subsample,
a = Specific Constants,
H = Hurst Exponent

The correlation degree of time series may be calculated by following Correlation Scale that presented by below; calculation with Hurst Exponent [Mandelbrot and Wallis, 1969; Mandelbrot, 1967; Rhee, 1988].

$$Correlation\ \ Scale = 2^{(2H-1)} - 1$$

Thus, when H = 0.5, and the Correlation Scale = 0, it is judged that the time series does not have correlation and 0 ≤ H <0.5 - rather, it shows fast convergence characteristics even if there is an external impact due to having negative correlation with previous data. And when 0.5 < H ≤ 1, it becomes long term memory of time series which is continuously influenced by impact, as the time series has positive correlation with previous data t, and the degree of such continuity increases as value of H becomes closer to 1 [Kim et al., 2004].

3.3 BDS Test : Non Linear Structures of Time Series

The BDS test verifies the non-linear data structure which was developed by Brock, Dechert, Scheinkman, and it is named after their initials. According to Chang and Kim [2002], the BDS test is a method that measures how densely the topological space will be filled by increasing embedding dimension, in given time series data through finding possibility that certain distance from one point to another point is arbitrary or smaller than value of the distance (ϵ). Generally, when random variable has IID characteristics, this variable fills topological space evenly when increase embedding dimension m. However, variables with chaotic characteristics cannot fill topological space evenly [Kim, 2003].

Correlation Integral is the probability function to measure the degree of filling topological space evenly and defined as the following equation.

$$C_m(\epsilon) = Number[(t,\ s)/\ \| a_t - a_s \| \ < \epsilon, t \neq s]/T^*$$

Where, *Number* = The number of pairs that satisfy the conditions,
T^*= All pairs that can be newly made by at with a_s from sample size T,
$\| \cdot \|$ = The distance between the vectors

Through correlation integral value (C_m) and scale ϵ, the Correlation Dimension D can be defined as the following.

$$D = \lim_{\epsilon \to \infty} \frac{\log c_m(\epsilon)}{\log(\epsilon)}$$

Thus, by looking at any changes in correlation integral value in the process of embedding a particular time series in the m-dimensional vector and increasing the m and ϵ at the same time, it can be determined whether time series data is IID process or having a non-linear deterministic structure. If the data is IID process, then the correlation dimension D which is derived from the integral correlation, will continue to increase – and if the data has a non-linear deterministic structure it will converge to a certain value. However, this correlation deterministic structure as correlation dimension requests close to infinitive data. To avoid this problem, in the case of time series data with characteristics of IID and $m \geq 2$, the relationship of $C_m = C_1^m$ is established. So, BDS Statisics W_m can be defined as follows.

$$W_m(\epsilon) = T^{1/2}[C_m(\epsilon) - C_1(\epsilon)^m]$$

If W_m is IID process, the expected value of $[C_m(\epsilon) - C_1(\epsilon)m]$ converges to zero as the length of the sample process grows – Brock et al. [1987] proved that – it would follow a normal distribution. Thus, when time series data is not a IID process, BDS test can determine presence of IID by estranging the gap between C_m and C_1^m generated when embedding dimension increases [Jo and Rhee, 2002].

3.4 Data

The estimation was performed as R&D activities' output and input variables. Input and output variables from R&D activities were extracted from Science and Technology Statistics Database. To start off, as an input variable, R&D Expenditure exists for the subject of analysis, and Total R&D Expenditure for national level of expenditure, Expenditure of Private R&D representing private sector's expenditure, Expenditure of Public R&D which includes public expenditure including the government's and public institute's. And Expenditure of Overseas R&D is foreign corporations' investments. As for types of R&D Expenditures – there are Expenditure of Basic R&D which is used for basic research sector, Expenditure of Applied R&D used for applied research sector, and Expeniture of Development R&D which is for product development. In terms of types of cost under

〈Table 1〉 List of Variables

Classification	Input Variables	Classification	Output Variables
Total Side	Total R&D Expenditure	Academic Side	Papers Published in SCI-level
	R&D Expenditure/GDP ratio	Industrial Property Side	Numbers of Patent applications
By Source	Expenditure of Private R&D		Numbers of Patent registration
	Expenditure of Public R&D		Numbers of Patent registration in USA
	Expenditure of Overseas R&D	Foreign Sector	Amount of Technology Export
By Type	Expenditure of Basic R&D		Amount of Technology Import
	Expenditure of Applied R&D	-	
	Expenditure of Development R&D	-	
By Type of Cost	Ordinary R&D Expenditure	-	
	Capital R&D Expenditure	-	
Personnel	Number of R&D Staff	-	

〈Table 2〉 Basic Statistics of Variables

Variables	Observations	Sample Mean	Variance	Standard Error	S.E of Sample Mean
Total R&D Expenditure	195	5.749191	16.853410	4.105290	0.293986
R&D Expenditure / GDP ratio	195	1.507190	12.589783	3.548208	0.254092
Expenditure of Private R&D	195	6.522360	59.391846	7.706611	0.551882
Expenditure of Public R&D	195	5.492934	41.905339	6.473433	0.463572
Expenditure of Overseas R&D	195	8.250422	1241.630386	35.236776	2.523358
Expenditure of Basic R&D	195	5.793115	15.120160	3.888465	0.278459
Expenditure of Applied R&D	195	5.625673	38.202924	6.180851	0.442620
Expenditure of Development R&D	195	5.987751	52.698032	7.259341	0.519852
Ordinary R&D Expenditure	195	6.050542	11.183890	3.344232	0.239485
Capital R&D Expenditure	195	5.524768	170.562012	13.059939	0.935242
Number of R&D Staff	195	2.784640	14.052359	3.748648	0.268446
Papers Published in SCI-level	195	4.814642	5.514047	2.348201	0.168158
Numbers of Patent applications	195	3.003541	26.647789	5.162150	0.369669
Numbers of Patent registration	195	3.701667	110.939530	10.532784	0.754268
Numbers of Patent registration in USA	195	71.287557	144144.138025	379.663190	27.188246
Amount of Technology Export	195	2.876980	96.762593	9.836798	0.704428
Amount of Technology Import	195	3.029342	66.440886	8.151128	0.583714

R&D Expenditures, there are Ordinary R&D Expenditure which is responsible for labor costs and consumable purchases, and Capital R&D Expenditure which handles apparatus and buildings. In addition, for variable of a labor force, Number of R&D staff exists under terms of Full Time Equivalent.

However, as for the results of Output Variables, Papers Published in SCI-level can be used which means numbers of papers published under Science Citation Index level academic journals. In regards to industrial property rights, a number of patent domestic applications, a number of patent domestic registrations and a number of patent applications made in U.S. were used as a variable. And as foreign sector variables, the amount of imports and exports of technologies were also used as subjects of analysis.

Time series data used for the analysis is an annually collected data, starting from 1963 to 2011 - accounting for 49 years of data. However, this time series data has to be expanded to determine characteristics of complex system, as the data was collected annually, as mentioned above. Therefore, using Benchmark methodology suggested by Boot et al. [1967] allows the extraction of quarterly data - 196 quarterly data, in this case. This methodology allows creation of benchmarked high frequency time series data by minimizing the sum of square of 1st differentials when high observation frequency within time series data does not exist.

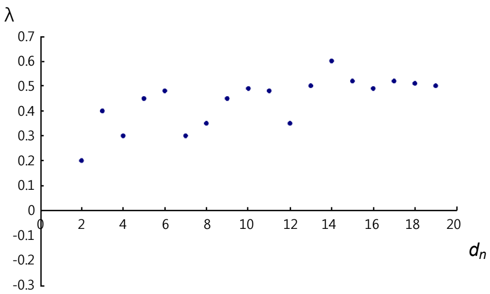
$$min_{t,h}[y_{t,h} - y_{t-1,h}]^2,\ s.t.\ y_{t,h} = \Sigma_{h=1}^{s} c_h\, y_{t,h}$$

where, y_t = low frequency data,

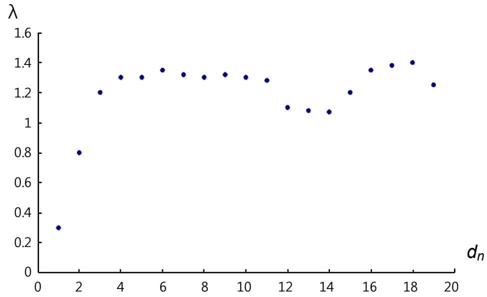
y_h = benchmarked high frequency data,

$c_h = 1,\ 1 \le h \le s$

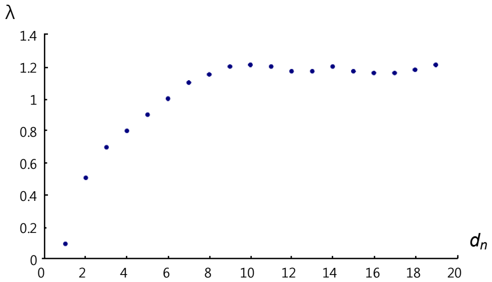
Total expenditure of R&D	Embedding Dimension = 1
τ = 0, 1, 2, 3	Lyapunov Exponent = 0.6411



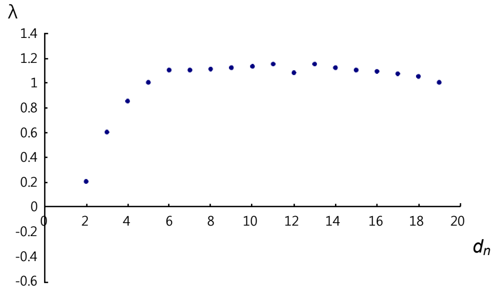
Private R&D expenditure	Embedding Dimension = 2
τ = 1	Lyapunov Exponent = 0.2901



No. of SCI papers	Embedding Dimension = 1
τ = 0, 1, 2, 3	Lyapunov Exponent = 0.7230



No. of Patents Applications	Embedding Dimension = 1
τ = 0, 1, 2, 3	Lyapunov Exponent = 0.6411



〈Figure 4〉 Results of Lyapunov Exponent Analysis

Based on previous data processing, percent change from previous period was deduced for the analysis. The basic statistics of these data are suggested as <Table 2>.

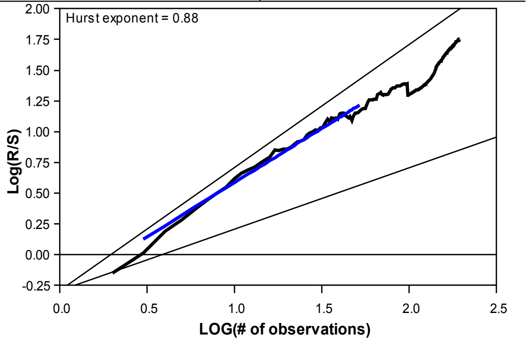
4. Analyses and Results

4.1 Results of Lyapunov Exponent Calculation

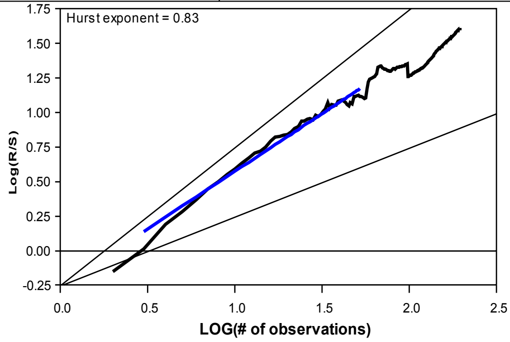
As the result of estimating Lyapunov Exponent aimed to input and output variables of science and technology activities, in terms of input, the presence of sensitive dependence on initial condition was identified in total R&D expenditure and private R&D expenditure, and in terms of output, the presence of sensitive dependence on initial condition was identified in the number of SCI papers and patent applications, respectively. Here, criteria to judge the sensitive dependence on initial condition is that the size of Lyapunov Exponent should be + value. These results are suggested as <Figure 4>.

Other variables such as R&D Expenditure/GDP ratio, Public R&D Expenditure, Ordinary and Capital Expenditure, Numbers of R&D Staff, Numbers of Patent registration, Numbers of Patent registration in USA, Amount of Technology

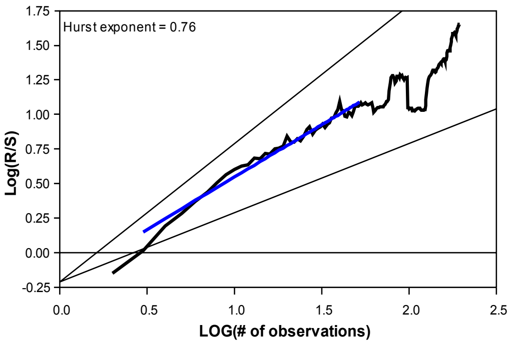
Total expenditure of R&D	Hurst Exponent = 0.88109



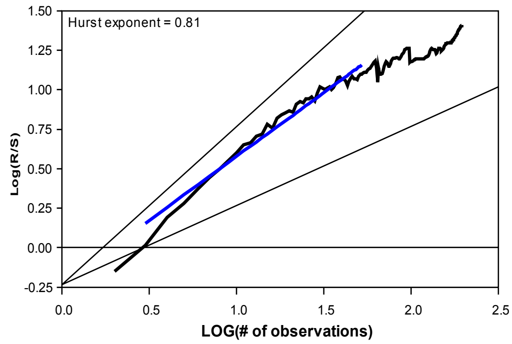
Private R&D expenditure	Hurst Exponent = 0.83424



No. of SCI papers	Hurst Exponent = 0.75718



No. of Patents applications	Hurst Exponent = 0.80985



〈Figure 5〉 Results of Hurst Exponent Analysis

Export, Amount of Technology Import shows no particular convergence value for their Lyapunov Exponents.

Therefore the four variables - Total Expenditure of R&D, Private R&D Expenditure, Numbers of SCI Papers, and Numbers of Patent Applications are the variables that are sensitive to the initial condition.

4.2 Results of Hurst Exponent Calculation

Using the four sensitive variables which had Lyapunov Exponent to be bigger than 0, Hurst Exponent was calculated to see whether external shock would continue in long term. The result of calculating Hurst Exponent confirmed presence of sensitive dependence on initial condition in output variables of SCI papers and patents application and the input variables of the total R&D and private R&D. Because the values of Hurst Exponent are 0.5 or more. These results are suggested as <Figure 5>.

4.3 Results of BDS Test

To check whether non-linear structure exists, four variables have been tested - which they all have Lyapunov Exponent to be bigger than 0, and Hurst Exponent to be bigger than 0.5. Baek [1997] presented that, to examine nonlinearity, 〈Table 3〉 Results of BDS Test

m	ϵ = 0.5			
	Total R&D Expenditure	Private R&D Expenditure	No. of SCI Papers	No. of Patent Application
2	-0.224	2.4239**	2.696***	0.597
3	-0.185	2.3834**	3.765***	0.641
4	-0.112	2.5069**	4.210***	0.544
5	1.2867	2.5736**	6.287***	0.485
6	2.001	2.4525**	7.255***	0.004
7	2.3811**	2.2811**	7.698***	0.306
8	2.5697**	2.1068	7.882***	0.223
9	2.6237***	1.9862	7.995***	0.153
10	2.5998***	1.8456	7.987***	0.934

using residuals after removing a linear structure by applying a linear filter to original time series. Accordingly, BDS test was applied on residuals after removing the trend of target variables with AR (1) process [Baek, 2007; Schreiber, 1999].

According to the result, in the case of total R&D expenditure, characteristics of nonlinear appear to be increasing as embedding dimension (m) increases, and conversely in the case of private R&D expenditure, as embedding dimension (m) decreases nonlinear characteristics appears to be increasing, respectively. And in the case of number of SCI papers, the non-linearity are strongly supported in for all embedding dimensions; while in the case of number of patent applications, the non-linearity cannot supported for all embedded dimension. These results are suggested as <Table 3>.

However, despite the fact that number of patent applications is sensitive to the initial condition and has long-lasting effect from external shock, but it has failed test of nonlinearity - hopefully the reason behind this irregularity can be identified in future researches. As it stands, though, the applications of patents represent the accomplishments from R&D; and simultaneously it is also a protective measure for a company's intellectual properties. Such characteristics of double-side might be the causation behind the above results.

5. Conclusion

As the result of test to verify presence of chaotic system in R&D activities by applying Lyapunov Exponent, Hurst Exponent, BDS test to 17 R&D related variables; it confirmed that total R&D expenditure, private R&D expenditure, and number of SCI papers have characteristics of the chaotic structure. It could be said, considering these results, although Korea has achieved remarkable level of scientific and technological development over the years, there are possibilities of unexpected results by change of external conditions.

Related to these characteristics, Rosenberg [1983] said that the uncertainty of the science and technology can be found in complex system of an aircraft. Despite abundance design and engineering-related data, as well as advances in CAD technology in recent years, it is difficult to identify the performance of the aircraft prior to its first flight, because it is difficult to estimate interactions between systems composed of many complex parts [Rosenberg, 1983]. Although these references are examples in the development of the individual micro-level practices such as aircraft or blast furnace, if these cases are to be accumulated in the process of firm's R&D, in the end, a country's R&D activities will eventually show unexpected results in macro-level.

In addition, looking at Korea's major export item is ordered as petroleum products, semiconductor, automotive, marine structure and parts, electronic sensor and flat panel display. In 2012, the characteristics of most of these items are based on state-of-the-art engineering technology with fierce international competitions taking place. And on the other hand, it needs to increase continuous R&D investment to sustain technological superiority. Thus, in order to maintain the technical superiority, more active science and technology related policy making should take place. Currently, the policies are being implemented in various ways to support private R&D expenditure in forms of tax benefits and such. However, Korea's export competitiveness is based on extensive research and technological development activities. Therefore more aggressive policy is necessary to create and support the R&D environment. From this point of view, for more sophisticated R&D activities as well as its expenditure, continuous efforts to develop effective training courses for R&D personnel are required.

In the other hand, as previously reviewed, the total R&D expenditure and private R&D expenditure, and number of SCI papers showed sensitive dependence on initial condition and long-term memory effects towards external shocks – often collectively called as the butterfly effect. When this assumption is applied, it is difficult to predict effects of relatively small obstacles or difficulties which appear in R&D activities in micro level on entire scientific and technological system in the country in the long run. Therefore, there is a need to develop policies that will alleviate the difficulties in procuring R&D funding. In addition, it would also be helpful if public and institutional apparatus can be setup to remove language barriers, in efforts to publish researches on an international level.

Thus, policy makers and research institutions need to expand efforts to broaden visibility, taking potential impact and dangers resulted from the individual technology development into account through constructing sophisticated predictive system. Through these efforts to construct such a broad technical prediction system, it should form the process to overcome difficulties and obstacles in science and technology system itself, by the self-organisation process or co-evolution process – which are another characteristics of chaotic system.

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Author Profile

Jeunghwee Loh

He received B.S. in Economics, M.S in Labor Economics and Ph.D of Science in Science and Technology Studies from Korea University, Korea. He is currently lecturer at Dept. of Economics, Mokpo National University, Mokpo, Korea. His main research interests include the relationship between science-technology and society, technological change and labor market, explanation of social phenomenon using econometric methodology. His research has been published various journals such as Productivity Review, Hanyang Law Review and Journal of Law and Politics research.