"Digital Earth" & The Research on Complexity of Economic Systems

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ABSTRACT The main idea of "digital earth" is the global information of the earth, which is an effective way to realize the goal of sustainable development. The study on "digital earth" indispensably includes the research of complexity. As an evolving complex system, economy is an important component of the earth system. Many ideas and methods attained in the study of complexity in the economy, which are valuable for reference, can also be applied to theoretical researches on other areas of "digital earth". On the basis of the understanding of "digital earth", this paper mainly discuss the following issues: the development of theoretical researches on complexity, the study of complexity in economic systems, and the relation between "digital earth" and the complexity in economy, i.e. how to realize information for the economic systems.

KEY WORDS Digital Earth, Complexity, Economy, Systems

"Digital earth" has been thought much of as soon as it was put forward, the main idea of "digital earth" is the global information of the earth. The research work on "digital earth" demands combination of several science subjects, because it not only is a simple technical program, but also it has holistic and social property. Now China is playing the stratagem of sustainable development and in the process of knowledge economy, so it has important science meaning and actual value that researching on "digital earth" in China.

"Digital earth" is an effective way to realize sustainable development .When analyze sustainable development, we think that it is a holistic conception (figure 1): The whole system includes three intersectional but relative absolute subsystems, i.e. re-source and environment sustainable develop-ment system, economic sustainable develop-ment system, social sustainable development system. The characteristic time of these three systems are apparent different, the time of resource and environment system is the longest and the time of social system is shortest.

Because there are many complex systems in earth system, the study on "digital earth" indispensably includes the research of complexity which is the foreland of modern science. Complexity research includes dissipation structure theory 、 synergetic 、 self-organization theory、catastrophe theory、 chaos dynamics and fractal, recently the discuss on self-adaptive system which re-present by Santa Fe Institute bring new thought and technical path for system theory.

1. Theoretical Research 0n Complexity

It is known that system is organized by several inter-actionable and inter-restrict parts which are called subsystem, system is integer that has some function, while systems are parts of the larger system which they belong to.

The complexity of complex system lies in six ways: 1 System is consist of many same or different kinds parts which affect system evolution differently.2 System is layered, the evolution phenomena of every level is not same, so development rule of levels maybe exist difference.3 The inter-actionable relation is strong, relation exists in different parts or levels, even in same level and part.4 The inter-actionable relation is nonlinear ,which is one reason of complexity and variety.5 The complex systems change with time ,their structure、function and relations are all dynamic. The dynamic evolution phenomena is the core question in complex system research.6 The complex system is open, which is a necessary condition. For stronger the adopting capacity, system intercommunicate material 、energy and information with complex environment. Many fields of nature science even social science belong to this category of complex system, such as geography system (include ecosystem)、life system、economic system、social system and so on .

The complex system research has important meaning in the science develop-ment of 21 century. In many subjects that are traditionally dealt with mathematical physical methods, such as chemical、physical、chronometer、geography etc, the complexity research is the foreland question. At the same time in the field that not

formerly popularly and perfectly played

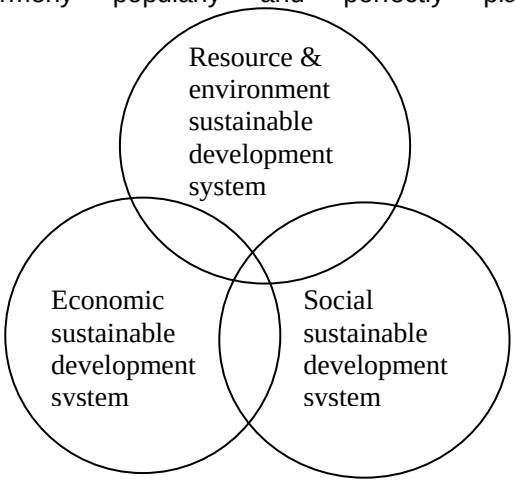

Figure 1

math-physical methods, such as biology and economy, the complexity research bring new thought and conception.

A deeply recognition to complexity began 70's of this century, the time space structure that far from equilibrium condition were found. The systems spontaneously product advanced spatial structure、temporal structure or spatio-temporal structure from formal relative out-of- order and low organization condition, such as the Benard convection in physical and chemical system、the evolution from out-of-order natural light to order laser、Belousov-Zhabotinski reaction. The reason of symmetry broken lies in interior of system, external environment only give and spring the condition when system product order, the orders or organizations are named self-organizations. Non-equilibrium self-organization theory discloses the basic principal and rule that exist behind changes from out-of-order to order, these principals and rules are useful in physic 、 chemistry and broad science fields such as biology even sociology. Dissipation theory and synergetic are the basic of self-organization theory, they both discuss system's evolution、 catastrophe rules that in nonlinear area far away stable condition. when exoteric system is far from equilibrium, many kinds of positive feedback inside system make out-of-order thermo-dynamic brand lost stable and product new order, at the same time nonlinear make system go to a new dissipation structure brand. The above process is realized by spontaneous symmetry broken. Synergetic finds the common rules that system produce order structure by analogy same phenomena, which break through formerly thermo-dynamic conception. One system that is consist of a lot of subsystems could form structure which has some function by the nonlinear interaction between subsystems on special conditions. In synergetic, the order parameter describe the macro order degree of system, the change of order parameter represent the change that system from out-of-order to order. Only few parameters have key meaning around critical point where order structure appear and control the system change result of function and structure. The synergetic is based on information theory、contrail theory、catastrophe theory and so on ,it describe the micro mechanism of nonequilibrium system change from out-of-order to order by combining statistic mechanics and dynamics, explains that the synergetic and competitive relations between order parameters and subsystems is the reason of forming self-organization structure.

In 80's,the fields of complexity theory was enlarge by research series of nonlinear phenomena such as chaos 、 fractal and poculation. Chaos shows the internal randomicity of deterministic system ,which breaks limitation of discussing random phenomena only from probability theory. The self-similar structure in chaos more disclose that there exist order structure in randomicity. The sensitive response of chaos to initial value or initial disturbs makes impossibility to forecast long-distance behavior. Similar with chaos ,the research on fractal、 poculation and all kinds of singularity、strange attractors make complexity theory deepen in all ways and use in a lots of material fields that include liquid、solid structure、life、ecosystem, even social and economic system.

Some basic characters of complex system, such as nonlinear、nonequilibrium、catastrophe、 bifurcation、chaos、path dependence and so on, are useful in many fields, which is the bases of the virtual development of subjects intercross. A series of basic methods to research complex system evolution is produced on the bases of system theory, which make us put forward new conception on the bases of thermodynamic and recognize the evolution behavior again. In the ways of mathematical and physical analyses, we could use mathematics models to build up dynamic equations to describe the evolution of system, pick up simple but relative maturity variables which have macro level statistic meaning to represent system conditions. When deal with actual questions, we could combine thermodynamic and dynamic concepts to qualitative and quantitative analyze system interaction mechanism and evolution behavior.

IN 90's, the research work of Santa Fe Institute in U.S. bring new idea. They consider the interaction between individuals、subsystems, then formulate behavior rules to form holistic macro structure, which is called emergency; then discuss the conditions that individual adjust itself's behavior to make whole system or individual best when external environment or internal mechanism change, which result in change of macro structure. With the formally method ,we could embody and program questions, formulate "game rules" on the bases of micro interaction mechanism, then program to realize by computer. This methods that formulate micro individual interaction mechanism is not simpler than the methods that build up differential equations, these two methods may united used when solute actual complex system evolution.

2.Study Of Complexity In Economic System

Economy is a complex system that is composed of many subsystems, including the factor of human. Evolution from individual behavior to the whole economic system will generate complexity owing to the behavior and idea of human, and the economic system is limited by the environment around, for instance natural resource and environment、social system etc.

In 1985,the author of dissipation structure theory I.Prigogine who had won the Nobel chemical prize brought the theory of self-organization in order to deal with the social and economic systems. In 1988,P.W.Anderson the Nobel physical prize winner and K.J.Arrow the Nobel economic prize winner took economy as an evolving complex system, in whose interior the dynamics mechanism may dominate the whole economic development. The essential regularity may hide under the complex system, and a few key variables and parameter can describes the dynamics mechanism. In 1991 the famous mathe-matician S.Smale brought that expanding general equilibrium theory to dynamic analyses is the main problem in economy, which gave an exact quantitative direction to studies of economic complexity.

Economy looks as an evolving complex system whose basic characters are multi-parameter、multi-objection、multi-level and high-coupling. The nonlinear complex interactions of internal factors determine the evolutionary phenomena of the system and the exterior environment affects the evolutionary state of the system. Special descriptor as following: The economic system is composed of plenty of economic factors, referring to a large number of variables and parameters that can influence the economic system to different extents, and complex interactions exist between system and environment or among internal factors .The economic system has its difference among the operational mechanism and mode at every level. The factors of system belong to different level, and different positions bring to different functions. What we are concerned about the macro-system and micro-system are different. To micro-system we are interested in optimization and equilibrium. To macro-system we are interested in the holistic evolutionary mode、the explanation and description of phenomena, including growth and fluctuation、inflation and employment. The micro mechanism behind the macro economy is the hot spot that is studied by the current economics. The complex interaction among the variables at every levels makes that the system organization and structure have complex functions. The economic system is not an isolated system, it will change substance, energy, information with the exterior environment, and in this procedure there may be complex interactions. The way that the system variables influence the system correlates with the exterior environment. The important resource of economic complexity is non-linear, there exist all kinds of positive and negative feedback and nonlinear economic relations, the nonlinear mechanism leads the economic systems to product a lots of complex evolution behavior on some condition. Because there exist random and uncertain factors in economic systems and environment, the system is not uncertain and the information is not complete, it is impossible to learn completely all information of the system, which put forward more questions to positively analyses to economic system evolution.

The economic system evolves dynamically. The system can approach to equilibrium or transfer from one to another. The whole system can change ,which introduce the variation of the system equilibrium structure, it is a nonequilibrium dynamic process. To deal with the dynamical evolution of the economic system, the non-linear economy dynamics is a main way. Applying the basic theory and method and correlating the stationary of dynamic equation with equilibrium, we can discuss the complex behavior of the system. If we need to consider the uncertain of economic system, we can build random differential equations to analyze. For economic system, we may give a set of differential equations as following:

$$\frac{dX}{dt} = F(X, \lambda)$$

Where $X=(x_1,\ldots, x_n)$ denotes system endogenous variable, $\lambda=(\lambda_1,\ldots, \lambda_n)$ denotes system parameter, F is non-linear function describing the evolving mode of the state variables. The above system is an autonomous system without time. When dX/dt=0, the system is under a steady state, which shows that the system state parameters do not change with time. When $dX/dt\neq 0$, the equation reflects the relationship between equilibrium and nonequilibrium and describes the system evolutionary path. We could solute or analyze (include numerical simulation analysis) the equations to get the qualitative description of economic complex system. In equilibrium theory, the optimum dynamic method is popular, i.e.

$$\max F(X)$$
$$s.t. G_i(X) = 0$$

this equal to a stationary evolving system, whose LaGrange and extreme value as following:

$$L = F(X) + \sum_i \lambda_i G_i(X)$$
$$\frac{\partial L}{\partial X} = 0$$

Economy evolution studies set on macro level; we need to build up a macroeconomic dynamics model which includes three main bodies (firms、households and governments) and three markets (commodities、finance and labor), and analyze the reciprocal relationship between various variables; Dynamics equations characterize how those variables evolve with time, therefore, reflect the phenomena of growth、fluctuation and equilibrium in the process of macroeconomic motion. This model provides an explicit macroeconomic evolution image for the important problems such as long run growth and short run fluctuation, the segment quality of economic growth ,the variation of economic structure. One sector model reflects the relationships among total amounts, growth 、unemployment and inflation are the main problems concentrated on one-sector model which does not involve the structure and mechanism of its sub-layer , and which is not sufficient to reflect the nature and depth of the economic phenomena . It is necessary to construct a two-or-three-sector model on the basis of the total amounts models to explore the mechanism of macroeconomic evolution further, meantime ,which can provide some new approaches and technologies to construct multi-sector models . And we can argue the problems of microstructure in macro economy. According to the difference of problems to be resolved, there are different decomposition ways, for instan-ce ,according to the product structure、region、production factor etc., correspondingly, there are industry、agricu-lture and service、city and countryside、physical capital and human capital respectively. This method can be used to the analysis of a certain valley or urban entirety, such as Changjiang valley、Shanghai city etc.

As far as the research of economics itself is concerned , economic growth and periodic fluctuation phenomena are the fundamental contents of macroeconomic system evolution. To the economy in China, it is significant to study how to maintain stable、healthy、rapid and sustainable growth and confront the challenge of knowledge economy in theory and in practice. Economy of China is unbalanced evolutionary, traditional equilibrium theory with linear and static methods are limited to use. We need synthetically to utilize nonlinear mathematics、non-equilibrium system theory, and computer simulation technique to explain and characterize the economy quantitively in the way of nonlinear dynamic models. At present, most of the national and foreign studies in the fields of economic dynamics centralize several important economic evolution phenomena, which analyze and explain specific economic problem more deeply, but regarding to the whole system evolution behavior, especially in the aspect of explaining lots of evolution phenomena (e.g. growth, periodic fluctuation) endogenously and without contradic-tion to themselves in the same model system ,is just begin. In terms of Chinese economy of the transition stage, various complicated economic phenomena often appear at the same time; in addition, because of the effects of global economy centralization and the stimulus of scientific and technologic progress in the world, new economic contents—such as financial crisis and knowledge economy—increase continuously, which enhance further the complexity degree of economic system and the correlation among sub-systems. So we must synthetical-ly put to use the theories

and methods of complex system to study every main aspect of economic evolution under a unified framework. In the study of economic system, the micro base of macroeconomic phenomena is always the front of economics; meantime, the relationship of systematic macro behavior and personal domain process is also the basic problem need to be resolved in the studies of complex system. Some simple and self-adaptable individuals can bring about the overall structure through the partial interactions and emergent properties which do not appear in the personal layer. This is an outstanding feature in the phenomena of self-organization of complex system. The deeply research to this problem not only can help us explain the pattern and approach of various complicated evolutionary behaviors which are formulated in the interactions of microeconomic individuals and grasp the internal mechanism of macroeconomic phenomena(e.g. growth, periodic fluctuation) even better, but also can help us strengthen the recognition and understanding to the complex system and the evolutionary regularity.

3. "Digital Earth" And The Economic Complexity Study

To the economic system, we study dynamic mechanism on its evolution 、the theoretical background of nonlinear evolutionary phenomena and analysis method in mathematics, build macroeconomic dynamic modal, look for the micro base of macroeconomic evolution and discuss the condition under which economy keeps stable development in China and the development of knowledge economy. The objection of the "digital earth" is to establish global high-resolution database, to provide information service and wide application. The economic system is an important part of the earth system. On the basis of understanding the complexity of the economic system , we classify、process and arrange the economic data, and establish an economic database according with the factual need. Then we build national economic information network and provide service for decision-making support.

On the basis of economic complexity, we can analyze the economic relation and behavior existed in the economic system, then apply mathematical and statistical method to build the model describing economy variables and structure, collect statistical data, estimate the model parameters, measure the economic relation and verify the result, thereby validate the theoretical base of the model and serve for economic explanation、economic forecast、structure analysis and policy estimation. In this procedure, all data including raw data and processed data are important, which are crucially prepared for the final economic informatization.

The economic system is a complex system which involves many economic parameters and economic relation. From the point of view of information, there exist many data about the economic system. But the information database we build finally is not simply the collection of all data, but an intelligent economic information system which is organized by the related data. Selecting the related data should be on the basis of the understanding of the economic system. We consider that there are some characteristic variables in the economic system, these characteristic variables could describe completely the economic condition, and we can unveil some system essential regularities by analyzing these characteristic variable in theory and in actual, for example, analysis of GDP and price index make us understand growth and inflation, analysis of capital K make us find investment I with its conjugate q and so on. The related data about economic characteristic variables can partly be acquired from raw statistical data directly, for instance GDP or population N etc, more data must be acquired by summary and process on the basis of theoretical analysis, for example K,H etc.

The above characteristic variables are concerned of the whole economic model. To discuss the micro mechanism about the macroeconomic phenomena, we must collect related data according to the multi-factors modal, explain and forecast economy in dynamical way. For every factor , we not only study the gross, but also consider coupling among factors and the effect to the whole structure. From the point of view of mathematics, we need more meticulous and more in-depth data according to different partition, for instance industry branch partition, area partition, production element partition etc. Beside these data about coupling among factors are needed. Oslo group in Norway has given us an example. They partitioned the whole economic system in 23 section in industry. Every section would find how to make itself optimization and how to make the gross keep balance. Under this condition, they found how to reassign the existing resource and determine the developing speed of all sections to realize the macro objection. When solute this econometrics model, not only the data of every sector but also the input-output relations between sectors are need.

A little data from the input-output table and the statistic yearbook could be used directly, moreover, the capital value and consumption function and so on need calculate by investment and consumption theory.

The above is an example of economic system, it explains how to process analyze and arrange the information of a complex object, and establishes the data system that is analyzed theoretically. In the example of economic system, even a complex object has a group of key variables, grasping this clue, we can organize all data resource organically. Among these key variables, quite a lot do not exist apparently, they must be acquired by deeply process. For example, "q" which determines the investment direction. In the procedure of data system expanding, we can go deep into all directions of the micro system structure and form a integrated information network. The analyzing data technology used in the economic system can be used in the earth system、the geographic system and the geological system etc.

4. Peroration

The earth system is a complex opening system. It takes on non-linear、multi-scale、self-organization、sequence and randomicity etc. Complexity study can provide theoretical context for "digital earth" technology. The earth system involves resource environment、society and economic system and so on. Economy is an evolving complex system. The theoretical study of complexity and the establishment of information database will take an active effect on spread of the "digital earth" plan.

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