METHODOLOGIES OF MODELING AND SIMULATIONS OF GLOBAL SYSTEMS

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Keywords: FUGI model, FGMS200, global modeling, bioinformatic economics, brain physiology economics, IT economics, global dynamic cooperation, AECS (automatic error correction system), self organization, fluctuation phenomenon, GEWS, soft variables, global simulation

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Summary

The FUGI global modeling system has been developed to provide global information to human society and to find possibilities for policy coordination among countries to achieve sustainable development of the world economy under the constraints of the changing global environment. The latest FUGI global model 9.0 M200 classifies the world into 200 countries and regions where each national/regional model is globally interdependent through international trade, financial flows, and information flows (see *The FUGI Global Model 9.0 M200*). Referring to the FUGI global modeling system (FGMS200), this article discusses mathematical modeling methodologies of complex systems, simulations of complex global systems and simulation techniques and software. FGMS200 software that can be run by Windows personal computer (Windows 2000/xp) is now available on request through E-mail: onishi@cgmfost.org.

1. Modeling Methodologies

The *scientific integrated economics* design concepts of FUGI global modeling system has been influenced by the advancement of information technology, biotechnology, and life science. The keywords are: (1) *bioinformatic* economics coupled with biotechnology and information technology (IT) economics; (2) *global dynamic cooperation* economics among the countries (cells); (3) *self-organization* economics in accordance with changing environment; (4) *automatic error correction* economics by adjusting estimated values with given data; (5) *brain physiologic* economics in collaboration with right and left brain; (6) *fluctuation phenomenon* economics considering alternative composite policy scenario projections; and (7) *global early warning* economics including not only hard but also *soft* variables. Quick policy prescription and coordinated policy actions might be feasible through early recognition of possible global risks, because the FUGI global modeling system will be able to provide up-to-date global information on alternative futures within a limited time span.

FUGI global modeling methodologies are influenced by developments in biotechnology and life science. Generally speaking, one type of methodology, known as the logical-thinking method, starts from a basic proposition, around which logic is developed to flesh out, so to speak, the relatively lean and simple starting point. The logical-thinking method is a reflection of logical thought processes, which have been found to predominate in the left hemisphere of the human brain. There is, on the other hand, the intuitive, pattern-recognition method, which seems to have an affinity for system structure and has been found to be associated with the right hemisphere of the brain. In a certain sense, what might be called comprehensive grasp or intuitive understanding belongs to this category of pattern recognition.

A combination of both of the above approaches is often needed in our conscious attempts to build theoretical models. Developing a logic in the absence of factual information, starting only from a given abstract proposition, will typically bring forth a theory that is full of illusions and lacks persuasive power as an explanation of factual reality. On the other hand, by wholly ignoring the logical-thinking method and paying attention only to the intuitive, pattern-recognition method, we may end up only with an array of facts, or a collection of cause-and-effect relationships. In this regard, then, it is necessary to attain a grasp of both the logical-thinking and the intuitive, pattern-recognition methods in a comprehensive way.

How to respond to this kind of problem has been a great difficulty for economists. In response to the challenge, econometrics entered the scene as a new analytical tool combining aspects of the traditional logical (deductive) and intuitive (inductive) methods. Econometrics is a scientific method combining, as the word suggests, economics and statistics. In other words, to make the science of economics more objective and scientific, econometrics may be said to have joined to economics the methods of stochastic, by first quantifying reality in terms of specific statistical data, and statistical methods, verifying the utility of a theoretical model. After World War II, econometrics achieved rapid progress and is a major branch of economics in all countries. In both the theory and practical applications of global modeling, especially noteworthy achievements in econometrics have been made by Lawrence R. Klein of the University of Pennsylvania in the US.

Since World War II, the trend toward greater interdependence of the world economy at the global level has progressed and is not limited to the export and import of goods and capital but has meant a strengthening of transnational, interdependent relationships also through exchanges of information, culture, and technologies. This in turn has encouraged economics to overcome traditional frameworks which were limited primarily to the economy of one or another single country. Klein, who initiated Project LINK at a global level, has in cooperation with universities, central banks, and international organizations developed a system to make short-term forecasts of the world economy, by means of linking national models by an international trade matrix. Unlike previous attempts at business cycle forecasts, which took as their objects of study the economies of single countries, Project LINK is distinguished by the fact that it carries out, from a global perspective, forecasts for the world economy (see *The Project Link Model*).

For this reason it may be called an appropriate methodology for the current global age. In the twenty-first century, people will no doubt see Project LINK and similar undertakings as ordinary things, given the further development of computers along with their software and peripheral equipment, and given the likely progress in technology for the transmission of large amounts of information using satellites and other new means. Econometrics has thus come forward as a powerful tool that radically supersedes former theoretical models based on abstract logical methodologies. Of course some structural parameters will have a high degree of stability over time, but econometric models nevertheless face the dilemma that certain of their structural parameters are indeed changeable, thus posing a problem in forecasting. Indeed, this type of *fluctuation* phenomenon seen in *life phenomena* always threatens forecasts of the future using econometric methods.

In a similar way, the appearance of complex and interrelated global issues such as environment, energy, development, peace and security, human rights and displaced persons, and so on, has posed problems whose solution is quite impossible within the traditional frameworks of economics.

Integrated life-supporting systems require a new methodology of *bioinformatic economics* (biotechnology + information technology + economics) beyond econometrics (economics + statistics). At the same time, there is increasing need for a new system design methodology on fuzzy systems that can manipulate *soft* variables.

These facts help explain why, since the early 1970s, research was begun on the design of integrated global models.

There has come into use an integrated global modeling which supplements this weak point in econometric models. Known as System Dynamics, or SD for short, it is the method used in the World System Dynamics Model developed by Jay Forrester, who gained rapid recognition for discussions of the model in the *Limits to Growth* report to the Club of Rome prepared by Dennis Meadows et al. (see *World3 and Strategem: History, Goals, Assumptions, Implications*). In his earlier book, *Principles of Systems*, Forrester explains the elementary principles of SD methodology, and examples of concrete applications are given in his works *Industrial Dynamics*, *Urban Dynamics*, and *World Dynamics*. Through his research he has attempted to show how useful the system dynamics method is for purposes of analyzing real social phenomena.

The most distinguishing point about the SD method is its seeing reality in terms of dynamic (i.e. active and continually developing) structures for systems. Systems used in such models have a number of variables, which govern the ways in which change *pattern* *recognition* methods take place in the past, present, and future. Because forecast information on likely future conditions is obtained by expressing the cause-and-effect relationships and then performing computations with this data, it is possible to offer prescriptions for action. Thus, another major characteristic of SD models is the ease with which practical prescriptions can be obtained through a dialogue between people and computers.

It is a fact that SD methods are the object of various types of criticism. Econometrics methodology has achieved in the years since 1950 qualitative improvements that truly beggar description. The building of models to reflect economic realities and their adaptation as a means of forecasting are both processes based on econometric methodology. As a consequence, methods of reaching statistical estimations have become precise. Information technology for large-scale data processing and the development and operation of computer models, which this technology makes possible, are difficult for untrained persons to approach and are in fact becoming quite specialized domains. Thus, *IT economics* (Information technology + economics) has appeared. In any case, the main distinguishing feature of econometric models is the fact that the models' structural parameters are inferred from real statistical data by stochastic methods. Compared with econometric methodology, the structural parameters used in SD models are not necessarily as appropriate, especially in the case of Forrester's world model, because his model seems to be too "deterministic," neglecting stochastic natures of the systems. Consequently, criticisms are often voiced alleging that with the relatively rough parameters used in SD models, forecasts about the future must therefore have a low credibility.

SD seems likely to be an outgrowth of old-fashioned Newtonian dynamics systems that are too deterministic to allow for stochastic fluctuations of systems. Furthermore, Forrester's world model does not classify the world into regions or country groups, so it cannot discuss global interdependence North-South issues. It is quite different from the Leontief World Input-Output Model where the world is classified into 15 regions to make policy simulation exercises on UN International Development Strategy (see *The World Input-Output Model (WIOM)*).

However, it is difficult to assert that these are fundamental faults in the SD method. This method's most outstanding characteristic lies in its comprehensive, intuitive grasp of social and economic phenomena as being a complicated loop of cause-and-effect relationships. In this process, there does arise the problem of how to estimate stochastic structural parameters as intermediaries in determining the cause-and-effect links among the variables.

In spite of these serious defects of not regarding stochastic phenomenon, the SD method, which can easily accommodate a nonlinear fuzzy system, may be said to be relatively versatile in comparison with the econometric method. Of course this is not to say that an econometric model is incapable of handling a nonlinear fuzzy system. But it cannot be denied that the econometric method has the disadvantage of being less flexible than the SD modeling method when we include noneconomic and nonquantifiable *soft variables* such as peace and human rights.

We are now faced with the task of deepening our understanding of the various methodologies and creating a new approach that includes the best features of all of them. The author should like to call such an approach, which will ideally exercise both the left and the right hemispheres of the human brain, a stochastic and fuzzy "dynamic soft systems approach" (DSSA), using human-intelligence oriented modeling. For purposes of making simulations of the future global economy it is necessary to quantify reality and make analyses by means of computer-aided modeling; yet there is at the same time a need to make qualitative analyses, i.e. scenario analyses because the future should have certain fluctuation phenomena (within the range of optimistic or pessimistic futures in accordance with human behaviors).

To gain a grasp of not just a part of economic reality but of its whole, a method of systems analysis is indispensable. The dynamic soft systems approach (DSSA) is indispensable for the analysis of a world in which the whole of socioeconomic-environmental reality is constantly changing and developing over time.

DSSA is an attempt to offer practical prescriptions by which we can respond to the "crisis problematiques" facing humankind, as Aurelio Peccei, founder of the Club of Rome, suggested. The prescriptions derived from a model of interdependent dynamic system structures, patterned after the real world and subjected to human-intelligence-oriented modeling, in turn allow us to elaborate probable or possible pictures of our world in the future, depending on various possible "scenarios" and "policy exercises."

Stimulated by our joint research with the UN University on a "global early warning system for displaced persons" (see *Refugees and Social Justice: The GEWS (Global Early Warning System) Model*), we have felt the need for our FUGI model to go beyond its present capacities centered on an econometric model (in the rather traditional, restricted sense of the term). We have therefore developed an integrated global model that can make future simulations of "global problematiques" or "global complexes of symptoms," including various types of environmental problems and the displaced persons issue. The FUGI global model is presently being expanded in scope to deal with such issues by using *bioinformatic economics*.

The FUGI model 9.0 M200 treats almost all countries, regardless of how large or small, as having the possibility of being dealt with as country units. It is designed to be a comprehensive system model that can deal not only with economic problems but also with incorporating subsystems to take account of environmental issues, population, energy, food, indicators of quality of life, and issues concerning human rights, peace, and security. Although our methodology is first and foremost based on various country or regional studies, we have felt it desirable, using these country or regional studies as a base, to adopt an orientation that further gives consideration to a highly sophisticated global modeling system.

The "dynamic soft system approach," derived from bioinformatic economics and IT economics, reflects the astounding development of information technology, particularly in the field of computers during the 1970s, 1980s, and 1990s. Extraordinarily sophisticated handling of information has become possible. In this regard, too, the software which computers use, that is to say utilization techniques, have made notable strides toward what we might call artificial intelligence (AI), artificial life (AL), and human intelligence (HI).

This approach is supported not only by the so-called soft sciences but also by developments in a number of interrelated fields of the frontier human sciences. For example, our understanding of the human brain has greatly advanced through developments in brain physiology. As a result, it is seen that the right brain perceives images of reality, while the left brain analyzes these in logical and conceptual ways and constructs logical models. As a part of its own division of labor, the brain's central ridge facilitates high-level flows or exchanges of information between the left and right hemispheres. Through a skillful treatment of the organically linked functions of the left and right brains, one can develop a soft system model. In a similar way, what we have tried to develop for our present purpose is not a model that merely collects information but a model that skillfully collects information, analyzes it, and provides a sophisticated global information system based upon *economics of brain physiology*.

The developments in life sciences are making ever clearer the conceitedness between individual cells of the human body and the human body as a whole organic entity. Individual cells contain information pertaining to the entire body. Thus, at times of special stress, the individual cells invoke a regulatory mechanism by which they pool their forces, working together in the face of difficulties. This is an extraordinarily important capacity, which living things possess, and we in fact need to incorporate just this sort of capacity into any global modeling system to prevent or mitigate, through international cooperation, undesirable phenomena in the global human society.

In our view, first-generation modern economics was based upon Newtonian dynamics and Darwinism. Second-generation economics was econometrics, which has been greatly developed through progress with statistics and economic modeling. The third generation might be called the dynamic integrated systems approach or bioinformatic economics, reflecting progress in life sciences, biotechnology, ecology, and soft system science.

In the twenty-first century, we may expect that economic models will come to have much softer dynamic systems. The information revolution, often known as the third wave, has had a great impact on the field of economic research, and through the extraordinary progress being made with computer hardware and software systems, great changes are being made in the traditional methods of economic research. With the advent of large-scale capabilities for data processing by personal computers, the FUGI global modeling system has become accessible to economists, and as a result we look forward to greatly improved capacities for research on economic theory and economic policies.

The making of policy proposals and the building of theoretical economic models, formerly dependent on professional economists with rich experience, sharp intuition, and outstanding capacities for judgment and analysis, can now, through intelligent expert systems, be achieved to a large extent by ordinary researchers. Consequently, what the author has created, the FUGI global modeling system as bioinformatic economics, is about to enter an age of global interdependence when it can justly claim pride of place as a traditional economic science.

2. Essentials of Mathematical Modeling for Complex Systems

First of all, essentials of mathematical modeling for complex global systems design the economic system as a core and then couple with other satellite systems such as population, food, energy, environment, peace and security, human rights, health care, and the digital divide (information technology). Economic activities have a tremendous impact on other sector activities around the world.

In mathematical modeling for complex global systems, we should make greater efforts to deal with soft variables in addition to the hard variables. The soft variables such as political variables might have much greater fluctuations compared with hard variables such as economic variables, which could be rather easily statistically quantifiable. Therefore we might design strong reciprocal feedback loops among hard variables but rather weak relations from soft to hard variables in coping with the instability of the whole system. Otherwise, we cannot make simulations of policy exercises with credibility.

Second, for optimum control of complex dynamic systems, it is necessary to include both increasing and decreasing forces properly in the systems. For example, in designing a nonhousing fixed investment function we should include not only the ratio of operating surplus to nonhousing fixed capital stock as a positive increasing factor, but also include the interest rate as a negative decreasing factor. The oil requirement function is determined not only by real GDP as a positive increasing factor but also relative to oil price and the use of alternative energy as negative decreasing factors.

Third, we live in a swiftly changing information society so that the theoretical model also should be quickly adapted to the changing world. Otherwise we cannot make reliable simulations using the model. Based upon new information and data, we should modify the model day by day and test its credibility. We should not insist on traditional economic theories but learn from changing reality to design new mathematical models.
Fourth, because mathematical modeling for global systems is complex, its computational process should be transparent. The computation process of the computer model based upon the mathematical model should also be transparent so that its validity might be shown clearly.

FUGI global model simulations can provide useful tools and play a role in providing global information for policy coordination exercises. In his own research on global models, the author has used an integrated systematic, starting from conceptual models to more complex theoretical ones, and then to computer models. The first generation FUGI global model of the 1970s has now developed into a human intelligence (HI) oriented new generation model, namely FUGI global model 9.0 M200.

Hardware and software development of high-technology computer systems supports global modeling. Methodologically, each new generation of the FUGI global model 9.0 M200 has represented a new frontier of economic systems science stimulated by new possibilities in computer science and also by discoveries in biotechnology and brain physiology.

This originally designed mathematical model is a product of logical thinking by left brain activities based upon information transmitted from the pattern recognition by right brain activities. This theoretical model can be transformed to the computer model by

using information technology (IT) economics.
During the period 1990-2000, the author designed on the basis of his knowledge on global modeling a significant new software system for FUGI global modeling system. Although this software system, named **FGMS** (FUGI Global Modeling System) 200, was researched and developed as a package for specific use in making computations for the FUGI global model 9.0 M200, it can be widely employed for analysis and modeling of the global economy or the economies of individual countries. The software system consists of databases **FUGIDB** and **FGMS200** that include controlling system files, estimating of structural parameters, simulations, and printing of simulation results in the form of world tables.

The FUGI global model 9.0 M200 classifies the world into 200 countries and regions where each national/regional model is globally interdependent through international trade, financial flows, and information flows. The 200 national/regional models incorporate nine major subsystems: (I) Population, (II) Foods, (III) Energy, (IV) Environment (Ecosystem), (V) Economic Development, (VI) Peace and Security, (VII) Human Rights, (VIII) Human Health Care, and (IX) Digital Divide (Information Technology).

In particular, the Economic Development system as a core includes 11 sub-blocs, as follows: (1) labor and production; (2) expenditures on real GDP; (3) distributions of income: profits and wages; (4) prices; (5) expenditures on nominal GDP; (6) money, interest rates, and financial assets; (7) government finance; (8) international balance of payments; (9) international finance; (10) foreign exchange rates; and (11) development indicators. The total number of equations is more than 150 000 for the M200 model.

The FGMS software system allows highly efficient, large-scale integrated global modeling. It is designed in such a way that the following operations are consistently carried out: (1) CONTROL, controlling the files of listing, loading, updating region and variables for the FUGI global model; (2) DSERVE, supplementary data service programs for updating and country, region data files; (3) ESTIMATE, automatic estimation of the model's structural parameters using OLS and MLBM; (4) SIMULATE, dynamic model simulation, testing, pre-projection, and projection using an automatic error correction system; (5) OUTGT, printing simulation results in world tables of 170 major variables, each country tables and world trade matrices; (6) UTILITY, receiving data from database FUGIDB to initialize and overwrite the time series data.

By applying this expert system on global modeling, the necessary manpower needs for global modeling and forecast simulation are kept to a minimum, and the work of computation is accomplished quickly and efficiently. In the absence of such progress in software, large-scale integrated global modeling and reliable policy simulations would probably be impossible to achieve. The **FUGIDB** and **FGMS 200** software for the FUGI global model 9.0 M200 are available for Windows PC (2000/xp).

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Biographical Sketch

Akira Onishi is Director; Centre for Global Modeling, Japan, and professor emeritus, former Vice President of Soka University, and an economics and global modeling educator. His academic background is in both economics and systems engineering. He has a Ph.D. in Economics from Keio University and a Ph.D. in Systems Engineering from Tokyo Institute of Technology. He had an opportunity to work at UN ESCAP and ILO, 1966–70. Then he served at Soka University, Tokyo, as Dean, Department of Economics, 1976–1991; Dean, Graduate School of Economics, 1976–1991; Director, Soka University Institute for Systems Science (SUISS), 1990–2001; Dean, Faculty of Engineering, 1991–1995; Dean, Graduate School of Engineering, 1995–1999; Vice President, 1989–2001. He served as President of the Japan Association of Simulation and Gaming, 1993–1997. He has received many academic awards: the International Biographical Roll of Honor to the Global Modeling Profession from the American Biographical Institute, US, 1989; the first Supreme Article Award from the Japanese Association of Administration and Planning, 1991; the 20th Century Award for Achievement from the International Bibliographic Centre, Cambridge, England, for Global Modeling, 1993; the Excellent Article Award from

ECAAR, 1997; the Japan Association Simulation and Gaming Award, 1998; 2000 Outstanding Intellectuals of the 20th Grand from the IBC, 1999. He was selected as one of the First Five Hundred in 2000 for service to Economic Science by the IBC. He is well known as an original designer of the **FUGI** (*FUtures of Global Interdependence)* model. The UN Secretariat, Department of International Economic and Social Affairs, adopted this model for long-term projections and policy simulations of the world economy from 1981 to 1991. During the period 1985–1986, he designed the Global Early Warning Systems for Displaced Persons (FUGI-GEWS) under the auspices of the UN Independent Committee of Human Rights. The UNCTAD Secretariat has officially adopted the FUGI global modeling system (FGMS200) for projections of the world economy and policy scenario simulations since 2000. The latest FUGI model 9.0 M200 as an integrated global model can provide not only global information on sustainable development but also on displaced persons or refugees, which might be seen as serious global issues in the twenty-first century.