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ECONOMIC BEHAVIOURS IN A COMPLEX SYSTEM

塩沢由典
Y. Shiozawa
Osaka City University

Economy as a complex system

1. Market or planned, an economy is a complex system. It is first of all a large scale system. Tens of millions of households and milions of enterprises participate in one national economy. The variety of commodities which are produced, distributed and consumed in an economy is also very big. There is no estimate of the number of commodities produced and sold in a capitalist country, but the Soviet Union counts up to 24 million commodities, which are officially quoted in a price list.

2. A complex system is not only large in its scale. It is complex in two senses.

3. In the first sense, it is complex as a system. In other words, it means that an economy is not an easy object for economic reseachers to study. There are always something which surpasses the analytical capacity of the economists. In natural sciences, such as physics and chemistry, a complex system has always something which refuses a complete analysis of its mechanism. An economic system is complex in this same sense.

4. But an economy is complex in a second sense, too. It is complex for human agents who acts in the economy. Complex systems in physical sciences lack this meaning of complexity. They are only complex for the researchers but not for the elements of the system itself. The complexity in the second sense has a meaning only for human (and animal) social systems. An economic system is one of typical examples of this kind.

5. Economic science has neglected for a long time consequences

of the complexity. In a textbook economics, exchanges are explained for a simple case of two or three commodities. All other cases are to be guessed by a simple extrapolation. It is supposed here that there is no big difference whether the number of commodities is small or big. But this is one of the biggest errors commited by the neoclassical economics.

Computing time of a maximizing problem

6. Let me disscuss an simple example. In the General Equilibrium Theory of the Arrow-Debreu type, consumers are supposed to behave according to the next maximization formula:

Maximize $u(x_1, x_2, \ldots, x_n)$
where $x_1, x_2, \ldots, x_n$ are all non-negative and satisfies the budget constraint:
$p_1x_1 + p_2x_2 + \ldots + p_nx_n$ is less than or equal to c.

7. If the utility function u is continuous and all prices p_i are positive, it is evident that a solution exists for this problem. But, the fact that a solution exists does not necessary mean that the solution is obtainable by calculation. Even if there exists an algorithm which solves a given problem, one has to say that it is practically impossible when the calculation needs too much time. And this is the case for the maximization problem which is just mentioned above.

8. Let us take a simple case where it is easy to estimate the length of calculation. Suppose that the utility function is additive for different commodities and saturates at the first unit for one and the same commodity. Suppose also that commodities are always sold by multiples of certain units. This changes the problem to a simple case of integral programming, which is nonetheless very difficult to solve numerically.

9. If I write down the new problem, it takes precisely the following form:

Maximize $a_1x_1 + a_2x_2 + \ldots + a_nx_n$

where x_1, x_2, ... , x_n are 1 or 0 and satisfy the condition:

$p_1x_1 + p_2x_2 + \ldots + p_nx_n$ is less than or equal to c.

10. A search of the maximum is not difficult. For each 0-1 vector $x = (x_1, x_2, \ldots , x_n)$, one has to check if the budget constraint is satisfied and compare for those which satisfy the condition the utility values. You can easily work out a programm which runs in a computer. A check time for each vector may be very short. Let us suppose that it can be done in a microsecond. The total computing time depends on the number of all 0-1 vectors. For a number n, there are 2^n vectors, for it is equal to the number of all combinations of n elements. The point is that the power function 2^n is rapidly increasing.

11. For small n's, the calculation goes well. In the case of ten commodities, the computing time is merely one thousandth of a second. For 20 commodities, it is just one second. But, for 30 commodities, the calculation needs 17 minutes. For 40 commodities, it needs 12 days and for 50 commodities, it needs more than 35 years. Before n arrives 100, the computing time exceeds all the time ever passed since the creation of the universe, that is, the Big Bang.

12. One may object that, if one choose a more suitable method of calculation, one can compute a solution in a reasonable lapse of time. This is a plausible objection. But this seems to be very difficult, for the problem which we are questionning now is but a "knapsack problem", famous in the theory of computing complexity and known to be a NP-difficult problem.

13. The theory of computing complexity is a branch of computer mathematics. It is concerned with the length of computing time and the space of necessary memories. It developped to a great exetent in 1960's and 1970's. The basic conjecture in this theory is that there may be no algorithm which solve a NP-complete problem in a polinomial time. This is only a conjecture, so it is not proved yet. However, there are good

circumstantial reasons to believe it. A NP-difficult problem takes more time than the related NP-complete problem. Therefore, if the conjecture is right, it is impossible to find a computing method which ends in a polinomial time of n.

Three kind of human limits in a complex system

14. Now, let us come back to the main stream of our discussion. I said at the beginning that an economy is a complex system. It is too complex for comsumers to be a maximizer. Even with the aid of computers, they cannot arrive to solve the problem if their task is to attain the maximum of thier utility. But, it is not necessary for consumers to maximize their utility. In order to survive in the world, it is sufficient that a minimal of the conditions of life are satisfied.

15. Then, how about the firms? In the neoclassical theory, firms are supposed be a profit maximizer. It is true that any firms, in a capitalist country, seek to increase their profit to the maximum. But, this does not mean that they can maximize their profit. The profit is something which comes out as a result. It is not a value of a function defined on a range of controlable variables. There are too many uncontrolable variables and only a small number of them are known to us. We can be a profit seeker but not a profit maximizer.

16. Even if all variables are known and supposed to be controlable, it is not easy to solve the problem of profit maximization. Many problems which arise in the production schedulings are known to be NP-difficult. If the variety of the products is a little big, it is not possible to solve them in a reasonable lapse of time.

17. Human inablity to solve a rationally posed problem was named by H. A. Simon as "bounded rationality". In his original version, he has given a little wider meaning to this term, but I prefer to limit the meaning of this term to this special inability. It is the lack of our capacity to proceed necessary

symbolical operation to find an answer. Logically speaking, the answer is already given, when a problem is posed, in the information of conditions of the problem.

18. There are other kind of inabilities which count much to the determination of our behaviours. One is the boundedness of our field of sight. We can only know a tiny part of the world. When I discussed the consumer's behaviour as utility maximizer, I supposed that a consumer knows the prices of all commodities. In fact, it is impossible for him or her to know even the prices of commodities which are sold in a Department Store.

19. Another kind of inability lies in the fact that we cannot control many variables at the same time. Suppose that a solution of our maximizing problem requires to regulate one hundred variables at a time, it is impossible to do it by one person. Even if you work in a team, the task may not be easy, for you need now a coordination among you. For this third kind of incapacity, I have given a name "boundedness of actions".

20. In sum, we have three kind of human incapacities. One is boundedness of our sight. The second, the boundedness of our rationality. The third, the boundedness of our actions. In a complex world called economy, all human agents are working with these three kind of boundednesses with them.

A proto-type of routine behaviours

21. Human agents are not maximizers. Not because they don't want to maximize their result, but because they cannot do so. Suppose that a man or woman wants to maximize his or her utility. He or she must know all the prices, solve the mazimization problem, and bid certain amount of purchase in every market of the product which is to be bought. But this is impossible, as our capability is bounded in sight, in rationality, and in actions.

22. In comparison to the complexity of the world, our capabi-

lity is small and limited. If we want to maximize the utility or profit, the problem becomes too difficult to solve and to implement. But maximization is not the unique way to solve the problem. A plan which is attainable is much better than the impossible ones. In the same way, a possible behaviour is better than an irrealistic maximizing behaviour. What are called routine behaviours are such possible examples.

23. A good example of routine behaviours is given by an ethologist Uexküll. In the introduction to his book(1) on "Umwelt", or environmental world for animals and human beeings, Uexküll tells us a story of the tick. A common tick which lives in a wild country can only reproduce when it can feed on the mammal's blood. But, how can it achieve such an act? A tick cannot see. It cannot move fast nor jump. How, then, can this incapable animal can succeed to suck the blood of a fast moving animal? The capability of the tick is so limited in comparison to the difficulty of the task. It seems impossible to solve the problem. But it is not. The following is what the ticks have discovered.

24. The tick's behaviour can be decomposed into steps.

(1) Climb a tree nearby and proceed to the tip of a twig.

(2) Wait until you smell the lactic acid.

(3) When you smell lactic acid, unhold your legs and fall.

(4) At the shock, walk arround.

(5) Do you feel warmth? If you do, go to the next step. If not, return to the step (1).

(6) Find a smooth place and prick the membrane with your mouth organ.

The smell of lactic acid is the sign that a mammal is passing by. Warmth means that the tick has succeeded to catch a mammal. If he falls in a cold place, he failed. It is easy to notice that these actions are programmed. This programme contains a branching and admits a loop when the tick fails to catch a target.

25. Parallels can be drawn between tick's programme and the

Turing machines. In fact, a Turing machine is a set of orders of the type qSS'q'. Here, q and q' designate an internal state of the machine. S is the sign which the head of the machine is reading. S' is an operation to write a prescrived sign in the place where the head is sweeping, or it is an operation to shift the head to the right or to the left by one block. The expression qSS'q' means the following. When the machine is in the state qS, execute the operation S' and transit to the state q'. In order that these orders are not contradictory, the set of orders should not include two expressions which start with the same first two symbols.

If we change the tape of the Turing machine to the nature in general, tick's programme can be interpreted as a kind of Turing machine. In fact, six steps descrived above can be re-written in the form of four term orders.

26. Many human behaviours can also be decomposed in the form of a sequential programme. In fact, many of technical knowledge can be reformulated in a sequential programme form. Let me give an example. Professor Nakaoka, well learned scolar in the history of sciences and techniques, cites an agricultural calender of later Hang dynasty (25-220 AD) as a typical example of old time techniques.(2) In the book called Sì mín yuè lìng, Cuī Shí wrote the directives to the peasants. The directives contain two parts. The first part indicate the sign of the nature to be remarked. The second part is the operation to be carried out. Here are two examples. (1) When the apricots bloom, till the light earth and suppress it later. (2) When the apricot blossoms fall, till the earth once more and supress it. Nakaoka thinks that this shows the structure of the agricutural technique of ancient times. Internal states are not indicated explicitly. But if we take into account that any operation has its proper order, it is easy to see that internal state change each time one opration is carried out. Consequently, one can consider the agricultuaral calender an representation of a Turing machine which operates in the nature.

27. I want to add that this type of knowledge is still valid

in the wide class of know-how. Cooking cards are usually written in this form of sequential directives. When to proceed to the next step is normally given by a change of signs of the nature. The same characterization is also possible for a major part of modern production techniques.

28. One of the most distiguished characters of programmed behaviours is that the agent is reading a very small part of the nature. In fact, in the above examples, ticks and people are reading only one variable at each step. In some cases, several variables may be cosulted, but the number of such variables is very small in comparison to the infinity of variables which may influence the comeout of the total process. This fact means that programmed behaviours have some different logic than the maximization.

Stionary process with fluctuations

29. It turns out that human behaviour is a series of routines and patterns. But this kind of behaviour is not always possible for any sort of environment. There are three important conditions which are required for the system.

30. The first is the stationarity. In order that a pattern is applicable, the system must be recurrent in time. This does not means that all the variables return to the same value at same time. When you want to boil the water, you put the water in the pot, put the latter on the gaz range, turn on the switch, and waits until you hear hissing of the steam. What is necessary in this operation is the certainty that the water boils when heated from the base of the pot by fire. If you count the number of seconds from the start to the boiling, it must change significantly depending to various factors. Instead of making this kind of precise prediction, one uses a sign of the nature (in this case, the hissing of the steam) to know if the water is boiling or not.

31. In economic lives, time is sectioned into units and each

unit repeats itself with great similarity. So, a day begins with the breakfast, commutation to the work place, start of the work at 9 o'clock, lunch at one, etc. etc. The same is true with weeks. You start to work on Monday and take a holiday in the weekend. Each year repeats itself in a remarkable similarity. This may be commanded from the seasonal change of the climate, but there are also repetitions ruled by the society. In Europe, an academic year starts on 1st September. In Japan, an academnic year starts on 1st April.

32. Economic activities as a whole are also repetitive. Recolts of the autum is stored and consumed through the year. In apparel industry you make the summer shirts in early spring and make winter coats in mid-summer. Despite of all this seasonal change of activities, if you see the economic activities through the year, the economy of a society as a whole reproduces itself from year to year.(3)

Economy is a loosely connected system.

33. The second condition which permits human agents to behave adequately in a complex system is that the economy is a loosely connected system. H. A. Simon called this condition ~~quasi-~~ near decomposability.(4) The idea is that if the system is the whole which cannot be decomposed into smaller and more controlable parts, one cannot know in which conditions we are, how the effects are related, and what it is better to do. Our bounded sight is usefull when a small part is relatively separated from other part. Our bounded rationality is usefull when the problem can be decomposed into that of a small system. Our bounded actions permit to control the consequences when the number of control variables is small. With all these reasons, decomposability of the world is the essential condition for the human behaviour to be possible.

34. Simon says ~~quasi-~~ near decomposability. I say loosely connected system. The reason of this crumsy wording is that any part of economic system is not completely independent from others.

Elements of an economy are interconnected with each other. When Léon Walras formulated his general equlibrium system, his intention is to clarify the effects of these interconnections. What he and his later folowers did not understand is that there are play in each connection and parts are only loosely connected. For a small scale system, this defference is not important. But, in a large scale system, the difference becomes important, for the time necessary for the simultaneous coordination becomes long and each part is enforced to proceed without any all arround coordination.

35. In order that an economy is devided into loosely connected parts, it is necessary that the economy is equipped with some devices which disconnect the parts. One of this decoupling function is fulfilled by the inventories, either in the form of material stocks or product stocks. Cases of optimal inventory policies were beautifully studied in mid 1950's by Arrow, Karlin, Scarf, and others.(5) In their study, they supposed stationarity and the quasi-decomposability, but they have not explicited these conditions. So many people understood that those were simply a special case of maximizing behaviour of an economic agent. In reality, they are most interesting case to be studied as a model of human economic behaviour.

36. Another important decoupling device is money. Money enabled to separate buying and selling. With this separation, mankind was liberated from the difficulties of double coincidence of needs.

Viability of the agents in the system

37. The third condition which makes people to behave after a routine in a complex system is the viability. If the requirements for the subsistence are very strict and if the people cannot live without attaining the maximum utility, then it is difficult for people to survive in a complex world. But, normally, there is no clear subsistnce level. If the situation becomes unfavorable, human being as well as other animals can

survive by lowering their stndard of life. The tick can wait for a very long period of time. By one experiment, a tick deprived of any supply of food and water could survive more than 18 years. Without this viability, the ticks cannot wait for a mammal to pass under the tree only by chance.

Conclusion

38. An economy is a complex system. In this complex environment, human ability is limited on three points: bounded sight, bounded rationality, and bounded actions. Maximization is not possible. The gap between the human capability and the task of achieving the maximum is too big. People follow routine behaviours. This behaviour is valid
only for a system which is stationary (with fluctuations), and loosely connected. Viability is the third condition which ennables the agent to survive without attaining a very high achievements.[6]

Footenotes

(1) Jacob von Uexkül & Georg Kriszat, STreifzüge duch die Umwelten von Tieren und Menschen, S. Fischer Verlag, 1943.

(2) Nakaoka Tetsuro, Ningen to Gijutsu no Bunmeiron (The theory of civilization concerning men and techniques), Nippon Hoso Shuppan Kyokai, 1991, p.18.

(3) Shiozawa Yoshinori, "The Primacy of Stationarity: a case against General Equilibrium Theory," Osaka City University Economic Review, Vol.24, No.1, 1989.

(4) H. A. Simon, Architecture of Complexity, Proceedings of the American Philosophical Society, No.106, 1962. Rep. in The Science of the Artificial, The MIT Press, Cambridge, Massachusetts, 1981.

(5) K.J. Arrow, S. Karlin, & H. Scarf (ed.) Studies in Mathematical Theory of Inventory and Production, Stanford University Press, 1858.

(6) For further discussions, see Shiozawa Yoshinori, Shijo no Chitsujogaku (The Science of the Market Order), Chikuma Shobo, 1990.