Evolutionary Economics in the 21st Century: A Manifesto

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1. Introduction

Japan Association for Evolutionary Economics (JAFEE) was founded in 1997. The membership mainly includes economists who are dissatisfied with mainstream neoclassical economics. In brief, evolutionary economics stands out in clear opposition (or "contestation" as in French in the 1960s) to mainstream economics. Those who espouse the ideas of evolutionary economics include Marxists, Institutionalists, Post Keynesians, and economic historians. This membership may not be much different from other evolutionary economics societies in North America or in Europe. As a new feature, JAFEE attracted many people interested in computer simulations. JAFEE membership focuses on developing and defining new evolutionary economics employing various methodologies.

Our organization should evolve to go one step further. A unified evolutionary economic theory should be presented. Moreover, it is necessary to clarify the reasons for the superiority of evolutionary economics over the neoclassical economics. Some important issues from evolutionary economic points of views have been abandoned by the neoclassical economists. New approaches towards these abandoned problems should be explored.

JEL: O30, O40.

* This paper is based on the presidential speech, read on March 28 in the 2004 Annual Conference of the Japan Association for Evolutionary Economics. At the occasion of the launch of the this Journal, this paper is prepared and written as a first draft of the research program by which those who are interested in the evolutionary economics may find out its common problems to solve, the direction to pursue and the goals to attain. Of course, any research program of a science should not be defined as an organizational decision making. It should come out spontaneously as a result of continuous discussions in which programs are proposed and criticized from within and from without. This paper is an invitation to such a continued discussion in the future. All propositions and opinions are my own and do not necessarily represent the opinions of the Japan Association for Evolutionary Economics.

Some people argued that there were no unified criteria on what constitutes evolutionary economics. Three topics are mentioned as fields of evolutionary economics: economic development, knowledge, and institutions. Other people claimed that the unity of evolutionary economics derived from the methodologies of analyzing dynamic and historical change and the genesis of institutions.[1)]

This article would discuss this issue from different perspectives. The unity of the evolutionary economics lies in its unique methodology: the observation of various economic phenomena from an evolutionary perspective. But this perspective alone cannot advance this field. From a renovation perspective, a new perspective and a new framework for economics should appear simultaneously.

This paper was organized as follows: In section 2, evolutionary economics will be defined. In Section 3, three categories of evolving entities are examined. A definition of evolution is given and tested. Importance of these categories provides us a good reason why economics should be evolutionary. Section 4 explained major aspects of selection process. Section 5 is devoted to an examination of the economic systems. Some modes of adjustments are discussed in this section. These sections present some reasons why evolutionary process is so widely observed and why it plays an important role in economies. Section 6 contains arguments on the nature of human behavior. Neoclassical concept of utility maximization is compared with rule-based behavior formulation of evolutionary economics. Section 7 exposes the close relations between knowledge and other evolving entities while the last section concludes that multi-agent modeling and simulations are good examples of new tools with which we hope to achieve a breakthrough toward a new stage of economics.

2. The definition of evolutionary economics

Evolutionary economics is a discipline that stands alone on its own theoretical basis and covers the views of how economy works and develops. For this objective, it is insufficient to criticize neoclassical economics. It is necessary to present alternative subject matter, theories, and tools instead of the neoclassical framework from its very foundations. This new framework and tools should be, on one side, a prolongation, and on the other side, a bold innovation of the long tradition of evolutionary economics. This paper is a rough sketch on ideas in pursuit of such a new evolutionary economics.

[1)] For Example, Susumu Egashira, in his tutorial session of the JAFEE 2004 conference, emphasized this point.

3. Typical examples of economic evolution

Three major economic categories are considered as economic objects whose development can be seen as evolutionary: Commodities, Technologies and Institutions. Two other categories, Economic behavior and Knowledge, were discussed in Sections 5 and 6. Behavior and knowledge serve as supporting basis for the first three categories. In this section our discussion focuses on the evolution of the first three categories. Cases of firms and organizations are more delicate. They can be interpreted as entities. They can also be interpreted as systems that contain many evolving entities. The related topics will be discussed in Subsection 3.5.

3.1 Commodities

In case of commodities, most manufactured commodities are standardized. However, commodities are modified from time to time.

Changes of car models may serve as a typical example. The Honda Odyssey, launched in October 1994, has undergone full model changes twice (1999 and 2003), and minor changes four times. In addition, eight new variants have been introduced. In one of the full model changes, the engine and styling are transformed entirely. Even the basic structure of engine can be replaced. When the Odyssey was changed in 1999, a V6 engine was introduced as an option for the parallel-lined four-cylinder engine. In one of the minor changes, the basic styling is not removed, but the exterior and interior may be altered. Bumpers, mirrors, sheet metal, wheels, panel displays, and colors can be easily substituted.

A variety of commodities are produced and consumed. In an industrialized country, the assortment is immense. Different commodities are counted as items. It is difficult to count this multitude of items. For example, two pairs of shoes, identical except for size and color, may be counted as separate or vice versa. Even though, a rough estimate is possible. For example, a standard convenience store may have a stock of 3,000 items; and a big department store as many as 150,000 to 300,000 items. In Japan, there are probably more than 100 million different commodities.

The set of all commodities used in a society changes from time to time. Some of them may become obsolete while others may be introduced. Some articles are modified or improved. New products will replace some old ones. Thus, the content of the set of all articles is always changing. Even when there is no change for the set of all articles, some products become more important because they are more in demand and therefore more of them are produced. Others become less important because they are less in demand.

The set of articles is closely related to the life of a culture, for they determine what is consumed and the kinds of activities that are possible. Therefore, how the set of articles changes is an important part of economic history.

Neoclassical economics continued to have ignored these important economic phenomena because no theoretical framework is available to be analyze in this evolution. Evolutionary economics provides a framework for answering these theoretical questions.

3.2 Technologies

The word "technology" usually represents a class of disciplines that can be seen as making up a single body. In reality, technology represents broadly diverse knowledge that tells how to transform goods, which one to choose as raw materials and how to use those products. Technologies are used in the design of machinery, the manufacturing of cars, robots, food products, and the exploration of medicines, to name only a few applications. These kinds of knowledge required for the production of commodities are extremely varied.

Technological knowledge is often structured and organized. It may be scientific or practical in its very nature. Some parts of knowledge, such as material mechanics and biotechnology, are important in the sense that they provide guiding principles for the development of new technological knowledge. Some parts of technological knowledge may be characterized as tacit knowledge which can not be formally defined in an explicit verbal form. A trained worker can do his job with extreme precision. Although the techniques he uses are not obvious, it is clear that he has them.

Technology changes for various reasons. For example, there are always new inventions, discoveries, research, development, experience in production and consumption, minor improvements, breakthroughs, and developments in science. New inventions often render old technology obsolete. Some technologies become outmoded and are abandoned. Thus, technology is a field where various elements evolve by various factors. In the field of the history of technology, we already have a good collection of monographs and articles. It would be a large undertaking to compose a catalog of the current works. It is remarkable that studies in the history of technology have a strong tendency to describe the technological development as an evolutionary process.

Neoclassical economics sometimes has treated technological development within its constrained framework. Using a method called growth accounting, Solow has discovered that a major part of economic growth is most often derived from productivity change. This has given a light on the importance of technology development in economic growth. The estimation of the total factor productivity became a big issue for interpreting Asian Economic Miracle, as in the case of Krugman's "Myth of Asia's Miracle" and debates after it.[2] It is, however, dangerous to rely too much on the result of growth accounting measurement. The premise of growth accounting is firmly connected with the neoclassical macroeconomic formulation. The Solow-type macroeconomic model treats the development of technology as a parameter only and does not enter into the details of the technology change.

Endogenous growth theory, a new variant of the neoclassical growth theory, treats technological development as an effect of increasing returns to scale of the predetermined macroeconomic production function. This may be a major improvement within the neoclassical framework. But this misses the real focus of the argument. There is no assurance that the macroeconomic production function takes that specific form assumed in the endogenous growth theory.

Real technological development lies in the change of production possibility sets at each production place. Neoclassical growth theory lacks a theoretical framework to connect microscopic technological development to the presupposed macroeconomic production function. This also means that neoclassical growth theory lacks suitable framework that can be used to analyze the technological development in general. Evolutionary economics, on the other hand, has no existing method to measure technological development. For the moment, we should be satisfied with the historiography of technological development but the measurement and theory are both important in the evolution of technologies.

3.3 Institutions

The word institution has multiple meanings.[3] For the purposes of this research, the word institution is used to define the norms, rules, and conventions that are generally accepted as a social code of conduct. Institutions are normal procedures used in negotiation,

[2] In this paper Krugman (1994) claimed that "Singapore grew through a mobilization of resources that would have done Stalin proud." This thesis induced many people to comment pros and cons.

[3] Hollingsworth (2003, Table 1) enumerates that in the common usage we can find following five meanings.

① institutions=norms, rules, conventions, habits and values

② institutional arrangements=markets, states, corporate hierarchies, networks, associations, communities

③ Institutional sectors=financial system, system of education, business system, system of research, social system of production

④ Organizations

⑤ Output and performance=statutes, administrative decisions, the nature, quantity and the quality of industrial products, sectoral and societal performance reaching agreements, conflict resolution, reporting and listening, and other business transactions. In some cases, options exist, but are normally determined by the culture. For example, in foreign trade, the choices for shipping conditions are limited to two; FOB or CIF, and a third choice cannot be introduced without adding complications.

A market economy is supported by a number of institutions. Even in simple procurement, it is necessary to understand the conventions for payment, shipping conditions, promissory notes, underwriting, bank discounts, letters of credit, and exchange rates. If one fails to pay bill in due time two times consecutively, he/she will face the cessation of bank transactions. The threatening of bankruptcy is a powerful social tool which enforce payment of commercial papers in due time.

Institutions form a network. One institution is supported by others. As mentioned above, payment at due time is enforced by the inter-bank agreement on the cessation of bank transactions. However, all institutions are not necessarily enforced by one kind of sanctions. Some norms and procedures are accepted as social standards or social customs, without any sanctions to enforce them.

Two institutions will often compete against each other. When commercial customs differ internationally, parties of different countries, if they want to come to an agreement, should choose which ones to use in their agreement. In this case, institutions are selected by the individuals. In some cases, choices may be different at each agreement. It may happen that one of alternative customs becomes a standard for international transactions between two countries. One may say that one of two competing institutions is selected by a kind of majority vote of the people. But it is important to note that it is not always possible to determine whether one institution is better than the other. Without considering the environment in which it functions, namely, the network of existing institutions, it is meaningless to ask which is superior to the other. In the process of globalization, we face many conflicts which arise from the difference of institutions of two concerning countries. Conflicts should be settled on the realization that any institution is imbedded in each country's network of institutions.

Sometimes new institutions are introduced. There are various reasons and occasions that new institutions are introduced to adopt a foreign institution, solve social problems, or adjust to a new lifestyle. When a new institution is introduced, it may compete against old institutions. Some institutions may become outmoded or irrelevant, and they may be excluded from the networks of institutions.

3.4 Core of evolutionary process

We have seen above three categories: commodities, technologies, and institutions. The elements of these categories undergo changes and the mode of those changes can be seen as evolutionary. These entities of commodities, technologies and institutions share all of the following common properties:

(1) They can be separated from others as a unit.
(2) They can be seen as something that retains their identities.
(3) They can be converted to others for various reasons.
(4) They can be reproduced in a way or another.
(5) They can be the targets of the selection.

These are major characteristics of entities that can be said to "evolve." The most delicate one among these properties is item (4) above, or reproduction. Copies are made and multiplied from a prototype. But each category has its copying mechanisms that are different from each category. Commodities are reproduced after prototypes. Each product is an instance of a commodity. Technologies can be transmitted from one person or firm to another, either by imitation, emulation or licensing. Institutions are transmitted from one community to another. Even though there are differences between copying mechanisms, these entities can be called *replicators* because they make copies of the originals.

Although there is no need to build up exact parallels between economic evolution and biological evolution, some common features can be observed. Economic entities can be seen as something similar to a phenotype. In the theory of biological evolution, each phenotype is supposed to have some physical base called genes. In the economy, entities that evolve may not have such physical bases. Instead, they are better seen as concepts. In the case of commodities, entity is the specification of a commodity. In the case of technologies, it is technological knowledge which enables people to get a specific effect of a product. In the case of institution, entity is a rule or a convention which is thought to be adopted in a determined case. Each entity can be realized in many ways: in a form of physical products, in a form of applications of technological knowledge and in a form of actions defined by a rule. Each of these realizations is called *instances*. For an entity, we define the population as the set of all instances which are realizations of the entity.

Evolution is firstly a process of the change from one entity to another. In this process, three different phases of evolution are involved.

(1) Mutation or change of entities, through inventions, discoveries, improvements, improvising, and others. The birth of new entities is a part of this mutation in a wider sense.

(2) Reproduction or spread and diffusion of entities from person to person or

community to community through emulation, imitation, licensing, introduction, acceptance, and others.

(3) Selection or differential growth of each entity, by selections within the market, through differences in the reproduction rate, by the judgment of engineers and decision-makers, by a political process, such as voting, and others.

It must be pointed out that the properties of the evolving entities do not exclusively determine the process of evolution. The whole process of evolution is a complicated chain of interactions. Competition between the entities of the same category is only a case of many types of interactions between the entities. We should be aware of interactions between the entities of different categories.

It deserves to note that, in the third phase, selections occur on the instance level rather than on the entity level. Take an example of consumers' choice, when consumers choose which goods to buy, their direct action is to buy one among several competing commodities. The selection of a specific mark adds one to the number of total productions of that mark. Sometimes this number may serve as the base of a decision if the firm continues to produce that specific commodities or cease to produce it. The entity level selection occurs only when this kind of decision is made.

Distinction between the entity and its instances may seem unnecessarily in academic details, but it is important to make this distinction in order not to make our discussion confused. Replicator dynamics or population dynamics is the analytical tool that deals with populations defined for each entity. Evolution is a changeover from an old entity to a new entity; It must include two processes: an emerging process, i.e. the population increase of a new entity and an extinction process, i.e. the population decrease of an old entity.

3.5 A cursory examination of firms

It would seem for many economists that firms or organizations belong to the category of things which evolve. To determine the way in which firms can be considered to be evolving entities, let us examine the five conditions presented in Section 3.4.

Firms are business units that can be clearly distinguished from others and retain their own identity through time (1 and 2). Firms change as a result of a reform or innovation in management and personnel changes (3). In a market economy, competition amongst firms is severe, and selection operates at the firm level (5). Four out of five conditions are easily satisfied. A special feature of firms is that it is not easy to determine whether they can reproduce or not.

In some special cases, we may say that firms can reproduce. Before 19th century, all firms were small and manipulated directly by the owners. A clerk who worked long time for a shop was given the right to open a new shop and became the owner of that shop.[4)] In this case, the operating know-how was transmitted from the parent shop to filial shops. Often the filial shops were permitted to use the same shop name as the parent. This form of reproduction is quite similar to the biological reproduction. But this type of reproduction is now rare. When the transportation and information system became developed, companies began to operate nationwide. For such a company, to make copies of it is to produce its competitors. Old reproduction system became unusual.

Now a company may open a filial company abroad and this filial firm will share in many respects common characteristics of the parent firm. But making filial firms may be better interpreted as an expansion of the same organization beyond the national border rather than as a reproduction of a firm. Another form of reproduction of firms is franchise chain system. Units of the same franchise, or franchisees, are quite similar to one another; they are instances of the original prototype or replicators. However, the chain center, or the franchiser of this chain, must fulfill different functions as the organizer, i.e. staff-training, supplying, controlling and marketing and others. A franchisee is not a copy of the franchiser. The reproduction scheme is very different from biological reproductions.

Typical reproduction scheme is not applicable to present day firms. Even if this is so, the concept of evolution can still be applied to firms. Some firms exist for a long time. During that time, directors will be replaced, owners may change, and main products may change. Even though, the firm retains its essential identity. Operation procedures, marketing know-how, production method, intra-firm education system, work style and many others are inherited from one time to another. Continuation of a firm is itself a reproduction of the firm through time. A firm does not multiply by reproduction but makes a copy of itself through time.

A firm can evolve by various forms. Some parts of operating procedures can be replaced by others. Wage system and other incentive systems can be modified. Even the work style of the personnel may change either intentionally or unintentionally. New behavior and organizational measures can be established as routine behavior and customs. They will be inherited just like “DNA” or “genes” of the firm. The change of these routine behaviors and customs are mutations of the “genes” of the firm. A firm can

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[4)] In Japan, this custom became a widely observed tradition under the name of “norenwake” in Edo period.

evolve with these mutations.

It will be useful to mention that the term evolution is often used to designate the change of two different levels: entity level and system level. In the case of commodities and technologies, the mutations are the change of commodities and technologies. In the case of firms, the mutations occur for components of a firm. When the components of the system change, the behavior of the system changes, too. This change of the system, which is a result of mutations of its components, is also called evolution. The evolution of a firm is that of the system level. However, the distinction between the entity level evolution and system level evolution is only a relative one. Commodities can be seen as a complex of different types of know-how's. From this point of view, the evolutions of commodities also bear the characters of the system level evolutions. In the following the word evolution is used both to indicate the change of the evolving entities and the change of a system composed of the evolving entities.

4. Selection process

The evolution is a complex process. For each phase of each category, the features and intervening mechanisms are different. Each process of each phase and of each category is dependent upon the others. For example, the evolutionary process of technologies affects the evolutionary process of commodities. The emerging of a new technology, such as information and communication technology, changes the bases of institutions. Institutions, which evolve through their own processes, create the ground on which commodities will evolve. Thus, the evolutionary processes cannot completely be separated from others.

Although economic evolution is a whole process, we cannot analyze it with one stroke. An examination of its development should begin with the studies of the process for each category. Entities, such as commodities, technologies, and institutions, go through three phases: mutation, reproduction and selection, as pointed out in Subsection 3.4. The mechanisms of the phases change according to what entities are being treated and what phases are being observed. When combined, there are nine cases. This paper will not discuss them. Instead, from Subsection 4.1 to 4.4, we will focus on the selection process in the market, Subsection 4.5 will introduce an important characteristic of systems: a system is either open to evolution or not.

4.1 Commodity selection: three moments

In a market economy, commodities are chosen three times. Firstly, they are chosen by producers. Many firms have a section or a project team whose task is to propose ideas or concepts of new commodities. Each firm has its own screening procedure, such as, a concept meeting, a technology review, or a feasibility examination. Few ideas are deemed feasible to be placed in the development process. In the course of commodity development, some ideas are abandoned because they may be too difficult to achieve within the given budgets. Some ideas can be modified in order to make the commodity more attractive. Normally, a board of directors discusses the new commodity and determines its readiness for the market.

Secondly, commodities are chosen by consumers at shops. Consumers examine the commodities and determine whether they are sufficiently attractive in terms of price, proposed utility, design, and packaging.

The third moment of the selection process occurs within homes or at the site where a product is used. Consumers examine its usability, durability, and others and determine whether a product is worth the price by using it. If they like the product, they will probably be repeated buyers. The manufacturer will then gain a loyal customer.[5)]

This selection process is quite different from the picture given by the neoclassical theory. In the neoclassical framework, consumers are supposed to have complete information for all commodities. Each of consumers has its utility function and is supposed to maximize the utility value for all sets of commodities which are available with the given budget constraint and the given price system. This assumption is equivalent to require infinite speed of calculation. The maximization problem is only a special case of *knapsack problem*, which is the most famous intractable problem in the mathematical theory of the computing complexity. The computing time necessarily to solve a knapsack problem increases with the exponential order of the size of the problem. The computing time for the maximization, even if you use a computer, easily exceeds a million years if you are to choose a combination among 100 items of commodities.[6)] The neoclassical framework thus contains a purely imaginative construction.

The evolutionary economics presents a totally different theory for consumers' selection. At first, consumers know very little about commodities. Their purchase behavior is a kind of random sampling. After a process of trials and errors, they come to know the relative utility of a good. They also come to know the prices of many commodities. When they are invited to buy a commodity, they know or can guess from

5) Umezawa (1997) emphasized the importance of consumers' evaluation in the use place.

6) It is supposed that a program is applicable for all systems of prices.

the past experience the usefulness of the commodity. They compare the expected utility with the price in the market, and if the ratio is better than the expected level (or the aspiration level), they decide to purchase the commodity. This is a very simple purchase behavior. The essence of evolutionary theory is in the evolution of this behavior. The utility level will be changed when actually using the commodity. The aspiration level will be changed when they happen to know the existence of the lower price offer. The purchasing behavior itself will be replaced by another when they come to know a better decision rule. Consumer's behavior is a result of a learning process. We cannot explain it without referring to consumer's past experience.

4.2 Market as a process

The market is where consumers and producers make their choices. As a major part of mainstream economics, standard price theory presumes the existence of a demand function for each of the consumers and a supply function for each of the producers. Moreover, these demand functions and supply functions are presumed to be transmitted to the market in an implicit way and the price of each item is fixed at a level where the total demand is equal to the total supply. The idea underlies all explanations from crossing diagrams of demand and supply curves to the sophisticated construction of an Arrow and Debreu-type general equilibrium theory. However, this picture is not only fictional and unrealistic but also misleading as to how the competition develops in a modern market economy.

In a modern market economy, almost all firms are endeavoring to sell as many of their products as possible. There is nothing that resembles a supply function. The notion of a supply function with prices as independent variables implies that a firm has a sales limit beyond which it does not want to sell at any given price level. However, the firms will usually be happy to sell much more than they are currently selling if they can sell at the actual market price. The supply attitude of the firms in a market economy is totally different from that suggested by the standard price theory.

As for the demand side, it is also doubtful that a demand function can actually be defined with prices as independent variables. The concept of demand function presumes that consumers can maximize their utility for any given system of prices. Actually, a consumer would be confused if all prices were to change at once. It is traditional, in the definition of demand function, to assume that consumers choose goods and services in such a way that they maximize their utility. As it is explained at the end of the Subsection 4.1, this is equivalent to assuming perfect rationality for consumers. Even if they try to maximize their utility, the calculation takes too much time until they get a solution.

Demand function and supply function have no solid foundations. They have been accepted only because they were thought to be necessary for the equilibrium framework. Equilibrium is a virtual state where there is no place for further adjustment. This provided a convenient framework for mathematical formulations. As far as mathematics was thought to be the unique tool which enables to analyze economic processes, equilibrium continued to be assumed as a unique framework. But it is time to stop to think from the equilibrium perspective. If the market is assumed to be a process of transactions through time, there is no need to presume that demand functions and supply functions can be defined with prices as independent variables. It is necessary to detach from the traditional image and switch to a new image of the market.

A typical transaction might occur as a customer walks around a shop to survey the goods and prices. The customer picks up some articles and shows them to the attendant. The attendant adds up the total price, and then the customer pays and exits with the goods. In this typical process, there is no haggling. Shopkeepers display commodities in their shops, and all articles have a price tag. This means that the shop is ready to sell the articles at the price noted. If a customer wants to buy the article at a lower price, the shopkeeper would refuse to make the transaction.

The price tags are usually fixed by a simple mark-up method. Roughly speaking, this is to add a constant rate of margin to the unit cost. Consumer selection determines the volume of sales. Within a certain interval, a day or a week, for example (this period may change according to the properties and circumstances of the commodities), the shopkeeper will replenish the sold articles by the procurements from wholesalers. The wholesalers do the same thing. They set prices and see how many they sell and procure necessary amount of commodities from producers. The producers, in turn, determine the production volume after the total sales volume realized in a determined period. Thus, the market is a process in which sales information is transmitted from one agent to another in a series. When materials, which are required for a production, are produced by other producers, information flow may form a cycle.

This whole process determines not the prices but the sales volume for each item. In a rough description, this determines the production volume for each consumer’s goods. Thus, the scale of reproduction of each item is determined as the sum of the consumer’s choice for each item. However, this is not a full description of the selection process.

After a period of time, one year, for example, the firm will learn the profit that it makes for each item it produces. Profit is the difference between the total sales and total cost. For any item, the total cost is principally composed of two parts: the constant cost and the proportional cost. Even when prices remain constant, the profit changes with the volume of sales. If sales exceed the breakeven point, a profit is made. If sales drop below the breakeven point, there is a loss. For a firm to continue to produce an item, it needs to expect to make a profit from its sale. If the realized and expected profits are insufficient, the firm may decide to exit the market. This is the second type of selection that the market imposes on the producers.

4.3 Price and the selection process

The preceding subsection does not imply that prices have no role in the selection process of commodities. Although prices play a very different role from the standard price theory, they are, at some point, an important factor in the consumer selection of commodities. Given that there are two products with similar qualities, but with different prices, in a shop, then the consumers buy the cheaper commodity. Thus, a lower price for a product may result in an increase in the sales volume of that product.

A lower sales price can be achieved by various means, for instance, lowering the margins; reducing the costs of shop keeping, transportation, and transformation; introducing superior transformation methods, and procuring products at lower prices. These activities are the substantive part of the price competition. Low price without these efforts may be effective for a short time but cannot be continued for a long time.

The low prices are not an unique method of competition. In a modern market economy, most firms want to sell their commodities more than they are selling now. Even if the total demand of the market is limited, there are normally two or more competing firms which can offer the same commodity or substitutes. Therefore, fierce competition occurs so as to attract consumers (or producers). In order to enlarge their sales volume, firms participate in many activities. For example, they put advertisements in newspapers and on TV. Sales promoters visit sales points frequently. A service center offers a warranty of free repairs. Discounts on products may be offered with or without a savings coupon. The best locations and shelves in a supermarket are eagerly sought. For luxury goods and services, brand image is important, and firms work hard to establish a good brand image for their products.

Firms are not passive when it comes to choose their product lineup. A firm may produce a product that is in the middle range and set a competitive price to attract customers because the mass production of the product will result in lower prices. Other firms may choose to produce a higher-end commodity, refine its processing, and attract users to buy its high-quality products at a higher price. In this strategic choice, the price is but one of many factors that the firms should take into consideration. Choice is made from the selection of commodity range, price, quality, production method, niche of consumers, supply network, service method, publicity method, and others.

4.4 Remarks on other selection processes

The market is not the only place where the selection takes place. The firms are mainly responsible for the selection of production methods. If there are two or more techniques that can be used in the production of a commodity, it is the firm that chooses the one from another to use. This choice is not always easy for the decision-makers. They must consider many factors. Even if one method were to cost less than the others, this would not guarantee that this method would remain competitive in the future. Each historical cost curve has a different decreasing rate, and a more costly method now might be a much less costly method in the future. A method which has a higher production cost for the product now on sale, may be useful for the development of new commodities, while another method with the lower production cost may not be useful for the development of new commodities. A successful development may change the destiny of a firm, but some continued research may be necessary for the firm to compete in a new market using the new method.

If the first phase of technology choice is made by the producers, the consumers will occasionally play an important role. When there are two methods by which we can realize the same function with slight variances, it is the consumers' selection that determines which is better and which one of the two technologies will survive the competition. The case of the competition for the videotape recorder (VTR) is well known. There was a fierce competition between two technologies for videotape recording, the Beta Max method of Sony and the VHS method of the Victor and Matsushita group. When the Matsushita group succeeded in the development of a 4-hour video tape, consumers started to buy more VHS recorders than Beta Max recorders. Ultimately, the VHS technology was the definite survivor.

Nowadays a fierce competition is deployed in order to get the world standard position for the protocols of their own group. This kind of competition is widely observed in the information and communication industry. The key word is compatibility. Usefulness of a machine is positively dependent on the rate of machines with which the machine is compatible. So the competitive strategy is to get users' support for machines of the own-side protocol as fast as possible. To launch machines faster than the competitors is the most powerful method of competition, for people who want to use these machines have no choice to make. When the competitors want to enter in the same market, the market is already occupied by the machines of the own-side protocols. Competitors must sell their machines against the disadvantage which is already established by the existence of machines of competing protocols.

4.5 Systems open to evolution

From an evolutionary perspective, planned and market economies are in sharp contrast to each other. A planned economy was strongly closed to evolution. The introduction of new commodities was not banned, but the procedures to achieve that were long and complicated. If one has an idea of a new commodity, it was not sufficient to persuade his or her superior. Planning procedure in a planned economy was made in a huge multi-layered hierarchy. In order to get the commodity produced, it was also necessary to persuade people who work in the ministry and people who work in the state planning authority. A planned economy requires a highly detailed program. A firm's product must be delivered at the right time and in the right quantity to the appropriate firm that needs it. Since the modern economy is a large network of outputs and inputs, any change of plans, albeit small, may require a change of the total plan. For this reason, changing an approved plan was avoided at all cost. The introduction of a new commodity or technology in the course of the planned period required the change of the plan. It should be avoided even if the needs were evident and urgent. So, practically, the introduction of a new commodity was possible only at the starting phase of a 5-year-plan.

A market economy has a different logic for adjustments. Owners of resources are free to exchange their possessions for others. An exchange is finalized if two parties agree. In a money economy, exchanges take either the form of buying or selling according to money paid or received. Production and sales are freely made at the risk of the owner of a firm. It is free to introduce either new commodities or new technologies. The future profit is a sufficient incentive for such an innovation. In this way, it is easy to make innovations in a market economy.

In order to compare these two economies in general terms, let us make a short roundabout. There are many artificial systems, from cameras to space rockets. They are all finely designed machines. In such a system, a minor change in the design may cause a malfunction of the total system. New designs require careful examination in order to assure good balances of various parts. They are systems rather close to evolution. But in the world of the artificial, a different type of systems was brought to existence. It is the Internet system.

The Internet is a worldwide network of computers. Each computer sends messages using an Internet protocol. A message is divided into packets. Each packet has an address in the tag line. Router computers search for computers with a specific address and determine the route in which the packet should be sent. As long as packets follow the Internet protocol, it is possible to send any information. The Internet system with digital multimedia technologies made it possible to send information in the form of pictures, videos, and sound tracks without any basic change in the protocols. The Internet is a system open to evolution.

The unique characteristic of the Internet impressed many scholars. Professor Hajime Kita of Kyoto University used the term “classical” to refer to systems before the onset of the Internet.[7)] Classical systems are not very open to evolutions. The Internet is the first system to be really open to evolution. Computer science engineers are now aware of the possibility of a system that is open to evolution.

Systems may be classified as to whether or not they are open to evolution. Of course, it is not easy to classify any given systems into two groups. Moreover, the word “open” should be better used in the comparative sense. A system can be more open to evolution than the other. The concept “open to evolution” is new but it must become an important concept of the systems theory.

If we use the above terminology, a market economy is open to evolution, whereas a planned economy is not. In the past, the debate on the reasons causing the failure of the planned economies has been a hot topic. The possible reasons of malfunctions of the planned economy include bureaucracy, lack of incentive system, inadequate price system, impossibility of calculation, and impossibility to use local knowledge. However, market economy was much more open to evolution than planned economy. This is the reason that the planned economies could not catch up with the advanced market economies.

The openness to evolution may be a key concept to be considered in the developing economies. The developing economies are not all the same. Each economy has its history, its people, its culture and its institutions. The difference of culture and institutions make some economies more open to evolution, while others less open to it. This difference can be a cause of different speeds of the economic growth. If evolutionary economics clarify the reasons of different speeds, it can be an important contribution to the development economics.

7) Kita (to be published). He is partly inspired by Ichikawa (2000).

5. Adjustment Process and Time

In the economy, everything is dependent on each other. This is true but this fact is often too much emphasized in economics. The use of simultaneous system of equations forces people to emphasize that some variables are dependent on other variables but this is a methodological assertion rather than a realistic observation. The same assertion can be made in physics but analytical framing is much different from that of economics. For instance, if one takes gravitation, for example, into consideration, everything is influential to the others. But, on many occasions, the influence of gravitation is thought to be negligible and treated as such in physics. In the same way, on many occasions, it is wiser to treat economic time series as an autonomous process than to treat it as a part of large deterministic process. Interdependence of variables is a kind of methodological myth made by L. Walras and other protagonists of general equilibrium theory.

Alfred Marshall had a much more realistic view than Walras, and he investigated problems using partial equilibrium analysis. He knew that the economy is decomposable. Simon (1969) pointed out that the world is almost empty and systems can be decomposed into subsystems. This decomposability is not only important in the systems designing but also in the theoretical framing.[8)] Needless to say, decomposability is not absolute. Any economic system is connected. The point is that this connection is loose. It is necessary to develop analytical frameworks which are suitable for these systems. This should start with developing two kinds of analyses in two directions: one is to develop a framework to investigate an independent process, and the other is to develop a systems analysis which provides us a terminology to discuss relationships between subsystems. An example for the first task is to treat a time series as an autonomous process with random fluctuations. The second task is more complicated and requires closer examinations.

5.1 Loosely connected system

If a set of variables form a decomposable subsystem, the time series of these variables form an independent autonomous process. The main difference between the process analysis and the equilibrium analysis is that the equilibrium is a state and nothing occurs in it whereas the process is a series of events and it proceeds only when something occurs. So the intervals of two events are important characteristics of the process.

Most of the economic process has a kind of rhythm which determines the standard

8) Partial analysis is not an easier substitute of the general equilibrium, but has an empirical basis concerning the systems working. See also Loasby (1991, pp. 48–51). Lachman (1986) pointed out the incompatibility of Marshallian analysis and general equilibrium (p. 20, note).

interval of two consecutive events. For example, a shop keeper replenishes his or her inventories regularly: everyday, every week, or every month according to the given conditions. These rhythms are not uniform for all processes. In the factory, some products on a passing line are produced with a tact time of several minutes. Production volumes per day can be changed everyday but they are usually controlled on a weekly basis. A decision on the investments on the factory capacities are much more important than the decision on production volumes per day but it is made less frequently than the change of production volumes. The price of a product remains fixed for a relatively longer period (e.g., a year).

In these processes, the rhythm and variables are the target of decisions. The most important fact in the above is that these variables are not determined at once. Each decision is made with proper intervals, even if these intervals are also a target of a decision making. A general equilibrium framework masks the simple truth that our decisions are made one by one consecutively in time. The general equilibrium presumes that all the variables are determined at once. This presumption is only necessary for the simultaneous formulation of general equilibrium and has nothing to do with the reality.

Economy is not a system in which each element is tightly connected to others like a solid body. On the contrary, economy is a loosely connected system. In this system, many of variables are loosely connected and have some freedom of variations. That is, if x is supposed to be a loose variable, and s is supposed to be the value of x at the moment, it can take any value in the interval [s-d, s+e] for certain margins d and e without causing any change for other variables of the system. It is only in this loosely connected system that you can make an effective decision. Otherwise, you are obliged to change many variables at once. But most of the time this is impossible, since the human ability to change many variables at one time is quite limited.

In the next section, the nature of human behavior will be examined. Whether it is economic or not, human behavior is normally a series of actions and each economic action is to change a variable or two. The economic actions are in these senses just adjustments of the situation rather than a control of the state of the economy.

The decomposability of the economy and loosely connectedness of variables are thus the basis of any human behavior. Systems' view of the general equilibrium theory totally ignores these facts and concentrates its interest on the interdependence of each element.

5.2 Decoupling mechanisms

For a system to be loosely connected there must be a mechanism which makes variables separated from others. This separation or decoupling is done by various ways. The most important one is inventory of stocks. In the case of a shop, articles displayed on the shelves and the stock in the backyard makes up the inventory. A factory has three forms of inventory: stocks in the form of raw materials, stocks in the form of work-in-progress, and stocks in the form of finished goods. All these stocks are most common means of decoupling.

Take the case of a shop. Customers come in from time to time and decide if they will buy this article or that. At each time when a customer wants to buy an item, the shopkeeper is ready to sell the item as much as the customer wants to buy. There is only one exceptional case that the shopkeeper cannot satisfy the customer's demand. It is the time when the amount that the customer wants to buy exceeds the stock of the item. In other cases, what the shopkeeper does is to pick up the required amount of the item from the inventory and deliver it to the customer. With the aid of inventory, the shopkeeper can make an action to sell an item. The same is true for the factory. Thanks to the stocks of various forms, each section of the factory can have its own speed of production. Of course, this freedom is limited, for we cannot accumulate stocks infinitely.

If the shop keeps no stocks, it becomes difficult for the shopkeeper to deliver an item when it was required. Suppose that we cannot stock an item in an ordinary way, like electric power for example. Then we cannot separate the production and the consumption and their decisions should be made at the same time. In an imaginary world where there are no stocks at all, every variable should have a fixed value as a function of all other variables. In this imaginary world, no coordination is possible, for we have no such power, even if we cooperate, to control at a time all the variables of an economy.

Another mechanism of decoupling is money. Money makes it possible for a person to separate buying from selling. Without money, it is necessary to realize the so called double coincidence of demands. This means that a person A wants to take an article X and give an article Y in exchange, whereas another person B wants to take an article Y and give an article X in exchange. It is very hard to find the pair of persons whose demands are in this situation. Money dispenses with this double coincidence and increase the chance to buy and sell. It is sufficient to find a person who wants to sell the item one wants to procure or to find a person who wants to buy the item one wants to offer. Promises are another form of institutions that have a decoupling function. If you make a promise to deliver commodities at a certain time, and if your counterpart accepts it, it will make possible to separate the time of transaction, the time of production and the time of delivery.

These decoupling mechanisms are material base for a human agent with limited capacities to make decisions and execute them.

5.3 Adjustment on different levels

As mentioned in subsection 5.1, each process has its own rhythm of events. When we are to examine two or more processes with different rhythms, the relations between them take a form of multi-layered adjustments.[9)]

For the concreteness, let us suppose that process A is the sales of a convenience store, process B is the replenishment of the stocks, and process C the change of assortment which is to be sold in the store. Then, process A proceeds at the rhythm of every few minutes, process B at the rhythm of every day and process C at the rhythm of every month. At each time a customer comes in and buys some of the items, the inventory of the store changes. The stock of each item decreases as the sales goes on. Each item is replenished at a determined time of the day after a report of the sales of the previous day. The initial stocks of the day are determined not by the shopkeeper but by the chain center. The latter calculate appropriate amounts of initial stocks every day for each item and for each store. At the end of the month, the center examines if an item is well sold or not. Then it decides if it continues to supply the item or ceases to do that. In these processes, three layers of adjustments can be observed. The stock adjustment of the convenience store is almost automatic. Each time an item is sold, the stock changes. The amount of replenishment can be adjusted by the center. For example, when an item often is sold out, the initial stock of the item can be increased. The adjustments of the assortment are made by the same center but less frequently than the adjustments of the initial stocks of each store.

For the owner of a convenience store, the set of items and the initial stock of each item are given conditions. What the owner can do is to arrange the articles in a good way on shelves and waits customers to come in. The chain center has to decide the initial stock of each item for each store. The series of daily sales gives the data for this decision. An adjustment of the assortment is another matter to be considered for the center. The basis of this decision will be the monthly sales for each item. If the sales volume of an item is insufficient, it will be replaced by a new item.

One may add another level of adjustment: the rhythm of replenishment. There is no reason that the replenishment cycle should be day to day basis. One can change it for example to twice a day basis or to once two days basis. The influence of this change will appear in various ways. One can choose the best cycle if he/she can estimates the effects

9) Multi-layeredness of economic adjustments is remarked by Nishibe (2004) and others.

of various cycles. The comparison may not be easy, for the effects of the change of cycles are often complex and competing. The change of roles is also possible. For example, the sales volume of lunch boxes depends much on school calendar. As lunch boxes occupy an important part of the total sales volume, it will be better to arrange in such a way that the supply volume of lunch boxes will be made by the shopkeeper rather than the chain center.

In this way, adjustments are made on various levels. Some of them are institutional in the sense that they are decided on the agreements of the interested parties. Some of them are conventional in the sense that the decision making routines continue to be adopted because they worked so far without any big inconveniences. Each adjustment rule concerns only a small number of variables and adjustments are done only on one or two variables.

5.4 Evolution and history

Theorists must be aware of equilibrium and maximization that are not an adequate framework for the examination of evolutionary process. Evolutionary economics requires a new theoretical framework which is totally different from the mainstream neoclassical theory. Without such a framework, it is impossible to show why evolution is important and why it is pervasive in every domain of economies.

Evolution occurs and is possible only in loosely connected systems. An adjustment rule is an example of economic behavior. It is a small rule in the sense that it concerns only a small number of variables. An evolution is a replacement of this small rule to another small rule. This explains partly why evolution occurs universally. Evolution changes the movements of only small number of variables. The risk of systemic failure is small. You can try any change on a trial and error basis. Effects of the replacement are sometimes difficult to determine. So the two competing rules can continue to co-exist for a long time.

A state of an economy can be described as a combination of many alternatives. A specific combination may occur only once for always. So the process of economic evolution must take the form of a historical. It is the succession of combinations of which each is unique for all time.

The importance of historiography should be emphasized. Economic history is full of examples of evolution. However, each economist only knows a small number of concrete cases of historical evolution. Natural history preceded biology and, in particular, the evolutionary theory. History of economics has followed a reverse order. The idea of evolution came from biology and the theory preceded the accumulation of knowledge.

Until now we have but rather poor collections. Yet it is evident that the collection of cases of economic evolution should be the base for further development of evolutionary economics. It is necessary to organize systematic efforts to collect samples of concrete evolution.

In 2004, the JAFEE started to edit and compile a handbook on evolutionary economics. Half of the handbook will be devoted to a collection of concrete cases. This is an effort, after the publication of a periodical in English, which requires the cooperation of all members of the Association. A handbook which containing almost all kinds of cases of economic evolution should have been published much earlier than now. But such an attempt requires an enormous work just like editing a dictionary or an encyclopedia. Only an academic association can achieve a work of such magnitude.

6. The nature of human behavior

Evolutionary economics gives not only a wider perspective to economic analysis, it is also a necessary framework for understanding the nature of human economic behavior and explaining how market economy really works as a process. Evolutionary economics is indeed an alternative to neoclassical economics as the core framework of the economic theory. In order to clarify this point, in this section we will examine the nature of economic behavior and in the next section we will examine the knowledge in relation to human behavior.

In Section 3, three categories of evolving entities were examined: commodities, technologies, and institutions. But it is not sufficient for evolutionary economics to investigate various cases of these categories. As mentioned in Section 3, there are two additional categories: behavior and knowledge. They are not only important as categories of economic evolution, but they are at the same time essential factors that support the mutations and reproductions of various entities.

As mentioned in Subsection 4.2, neoclassical economics has accumulated theoretical anomalies. It is evident that economics requires a paradigm change. The necessity of this change has been recognized since 1970’s but economics has failed in doing so, because it could not abandon the theoretical framework of neoclassical economics and could not present an alternative framework. The neoclassical framework is composed of two principles: the maximization principle to characterize human behavior and the equilibrium framework to characterize normal economic state. The common understanding among evolutionary economists is that the equilibrium framework should be replaced by the process analysis and the maximization principle by the routine behavior and selection process. Thus the correct understanding of the nature of behavior is the crucial part of evolutionary economics. Knowledge and behavior are closely linked. Indeed, knowledge and behavior are the face and back of the same coin. Although it is difficult to examine knowledge and behavior separately, behavior will be examined mainly in this section and knowledge will be briefly examined in the next section.

6.1 Maximization principle reexamined

Let us first examine the nature of human economic behavior. This is a field in which the neoclassical economists feel at home and are confident of their theory. Alternative view of how people behave should be presented from evolutionary perspective. The conclusion reached in this study is that economic behavior should be understood as an application of a rule of conduct. Most evolutionary economists have come to support this conclusion. The contribution of this paper is that rules of conduct, decomposed into its simplest form, have a specific structure which is named as "CD transformation" by Tamito Yoshida, an emeritus professor in Tokyo University. This will be explained in Subsection 6.3, but it will be easier to understand the range of this characterization when we start considering the explanations given by neoclassical economics on consumer's choice.

Suppose that a consumer chooses what to buy in the market. In such a situation, neoclassical economics postulates that the consumer follows the maximization principle. Mathematically speaking, the problem of consumer's choice is one of simple maximization with a constraint condition. When the prices are positive, the set of non-negative points, which satisfy the budget constraint, is bounded and closed. Any continuous function has a maximum point on this set (Weierstrass theorem). Once this explanation is given, neoclassical economists are quick to conclude that people choose the maximal utility combination of goods because there is no reason to choose less attractive combinations. However, there is a big gap between the existence of a maximum point and the possibility to find the maximal point. As mentioned in Subsection 4.1, the time necessary to solve the problem increases by exponential order with the number of goods, and it soon becomes impossible to solve.

In textbooks, which are used in an introductory economics, figures of the case of two items are given. Finding a maximal solution does not seem difficult at all. In the general case, a system of equations is given, as well as an explanation that states that, at the maximal point, specific conditions must be satisfied. However, no explicit explanation is given for finding the maximal solution. Neoclassical economics systematically neglected the computing complexity of the problem and ignored logical consequence which is easily derived from the fact that the computation requires too much time to solve the problem. To postulate maximization principle is irrational when it is known that the maximal solution cannot be found.

H. A. Simon was the first to question, following the theme of bounded rationality, how individuals behave when unable to calculate maximal solutions. Bounded rationality can be defined as the condition that the computing complexity should be within the range of human reasoning.

Only one extra remark is necessary here. Owing in part to Simon's first formulation, bounded rationality is often interpreted as something that is related to uncertainty. The neoclassical approach to this situation is the expected utility version of the maximization principle. Before an evolutionist's understanding of behaviors is presented, it will be necessary to examine the case of expected utility maximization.

6.2 Expected utility and uncertainty

The world is complex, and it is difficult to foresee the consequences of specific actions. In such a situation, theoreticians have a tendency to formulate the problem in a stochastic form. They assume that people maximize the expected utility. This is a simple repetition of the error of the maximizing principle. In a new situation, the conditional probability of each outcome will not be easily known. Expected utility for each set of alternative actions is the sum of the utility of each outcome multiplied with the conditional probability of the outcome. Without knowing conditional probabilities, how is it possible that people estimate the expected utility?

Suppose that all possible outcomes are known (this is not always the case). If the problem is small, the expected utility for all alternative actions can be calculated. When the size of a problem is a bit large, the work becomes difficult, for it is necessary to enumerate all the combinations of different actions and estimate the conditional probabilities of each outcome for each combination of actions. Even if this is done correctly, the maximal solution does not assure that the outcome is substantively better than the outcome expected by the rule behavior.

For clarification, let us assume that there are five consecutive choices with three options each. As a result, the total number of combinations is 3^5, i.e., 243. Let us also suppose that the same decision-making situation has occurred 100 times. Since this is a situation that occurs infrequently, this number of experience is significant. But an occurrence of 100 times is insufficient in order to estimate the conditional probability of an outcome for each combination of choices. For 243 combinations, we only know 100 cases. Many of the combinations had never made in the past. How can we estimate which outcome will follow in what probability for each combination of choices? Except in cases in which the outcome can be determined by the laws of physics, the probability estimates are purely subjective. The expected utility, based on these estimates, is a kind of pure imaginative guess and has no connection to reality. As a result, the maximal solution will have no substantive meaning.[10)]

6.3 Rule-based behaviors

It is clear that the maximization principle should be abandoned. We live in a world where complex problems are most often posed. But except in very simple problems, the pursuit of a maximum is practically impossible. The question of how individuals behave in this complex world arises.

It is necessary to approach the question from a totally different angle than maximization. There are many hints for this. Behavioral psychologists analyze human behavior as a combination of stimulus and response. Whether it is the result of classical conditioning, after Pavlov, or of the result of operant conditioning, after Skinner, behavior is a combination of a stimulus and a response. Evolutionary economists talked much about routines and rule-based conduct. Computer scientists formulate human behavior in a computer program. But no prototype of human behavior is so far given. Any complex behavior is composed of several actions of a simple type. When we know this simple form of human behavior, we can examine, in a general way, the nature of human economic behavior.

Such a formulation can be given in the form of a quadruplet: $qSS'q'$. Here, q indicates the internal or physical state of the actor, S, the observed situation or stimulus, S', the action to be taken, and q', the internal or physical state of the person after action S' has been taken. Stimulus S comes from the outer world, and S' is an action to the world. Here, "the world" refers to both the external world and the actor's internal world.

The formula given above is too abstract. An illustration will be necessary. Any conditioned reflex is given in a form $qSS'q'$. For example, take the famous reflex test. In this case, q is the state that leg is free to swing, S is the stimulus given by a hit of a hammer on the knee, S' is the unintentional kick forward, and q' is the same state as q. When you hear the alarm clock rings, you know that it is time to wake up. In this case, q

[10)] This point is once discussed in Shiozawa (1998). Expected utility maximization, as well as simple utility maximization, is in the realm of "physical symbol systems hypothesis" (Newell and Simon, 1976). One may perhaps say that they still remain in the cognitivist view of representation (Ziemke and Shakey, 2001, p. 62).

is the sleeping state, S is the alarm of the clock, S′ is the directive that you should wake up, and q′ is the state that you have get up already.

The essence of the formula is as follows: Directed by the internal state one examines if the outer world is in state S; if it is, one acts as the directive S′ dictates and change his or her internal state to q′. What the actor does at a specific time is very simple. He or she does only one thing: observe if the world is in state of S or act as S′ dictates. No specific level of intelligence is required to perform this action.

Quadruplets can be divided into two parts: qS forms the conditional part Q and S′q′ forms the action part A. Then, we can rewrite the quadruplet in a form of couple QA or $Q \Rightarrow A$. The quadruplet then gives an if-then rule: if qS, then S′q′, or, if Q, then A. This is the prototype of rule behavior. After a careful examination of American semiotics, Tamito Yoshida (1990, original paper 1967) interpreted this formula as CD transformation, i.e., a transformation of a cognitive meaning to a directive meaning. John Holland's "classifier" has a close relationship to if-then rule conduct or Yoshida's CD transformation.[11] This subject will be dealt with later again.

If-then rule formula is a useful expression as independent behavior. But this formula cannot include information of how to unite different CD transformations and to organize them into a series. The ingenuity of the quadruplet formulation lies in its ability to express a series of actions as a set of quadruplets. In fact, let us consider the series of actions briefly written below: If S_1, A_1. Then, if S_2, A_2. Then, if S_3, A_3. If we introduce internal states q_0, q_1, q_2, and q_3, this series of conditional actions is described by the following set:

$$q_1S_1A_1q_2, \quad q_2S_2A_2q_3, \quad q_3S_3A_3q_3.$$

The actor starts from the internal state q_1. If S_1 is observed, the actor takes action A_1 and transits to the internal state q_2. Then, if S_2 is observed, the actor takes action A_3 and transits to q_3, which means the end of this series of actions. This formulation was found in a guide book on computation theory.[12] It was surprising to learn that any computable function could be written as a set of quadruplets of this form. As a particular case, any program in a computer can be written as a set of these quadruplets. This fact assures the universal character of the quadruplet formulation. Although it is highly abstract, the formula is well designed and applicable to human behavior even in a complex

[11] Classifier systems are explained in many papers. For the explanation by Holland himself, see for example Holland (1992) or Holland (2001).

[12] I found this formulation in Martin Davis (1985), Definition 1.2 in Chapter 1.

situation.[13)]

6.4 An illustration from daily life

Any behavior can be decomposed into a series of if-then-type actions. Take, for example, the act of making coffee. It can be broken down into a series of instructions, as follows: Measure two cups of water into a pot; place the pot on a heat element; turn on the heat; place a paper filter in the drip strainer; place a suitable quantity of ground coffee in the filter; place the strainer over a coffee cup; wait until the water boils; when the water boils, pour it into the strainer; wait until the water passes through the filter; remove the strainer; add milk to taste to the coffee; pick up the cup; carry it to the table; and enjoy the coffee.

This is a series of actions, each of which is conditioned by prerequisites that should be satisfied as a result of previous actions. This series can be decomposed into a set of quadruplets in which the internal states q and q′ play the important role of assuring a good order of actions.

Even animals with low intelligence behave in the similar way. Jakob von Uexküll (1934), the founder of biosemiotics and inventor of the Umwelt concept (species' proper environmental world), gave a classical description of tick's egg laying behavior.

For a field tick to lay eggs, it is necessary to suck the blood of a mammal. But tick's abilities are quite limited. It cannot move quickly. In contrast to the flea which can jump hundred times higher than its body, the tick cannot jump at all. In addition, the tick is almost blind. At first thought, it seems impossible for a tick to catch a mammal and suck the blood. However, an ingenious solution has been found by the tick. When a tick is ready to lay eggs, it climbs up a bush tree and hangs at the tip of a branch. It waits for a long time, even years, until it smells the butyril acid. This material is secreted from the skin gland of mammals. When a tick detects the butyril acid, it releases the branch and simply falls. In a fortunate case, the tick falls on a mammal. It moves around and, when it encounters a warm surface, it bores into the skin of a mammal and begins to suck the blood.

This tick's behavior can be decomposed into a series of simple actions. The first action is to detect the butyril acid and let the body fall. In a form of quadruplet, q is the waiting position, S the detection of the butyril acid, S′ the freefall, and q′ the readiness to catch whatever it falls on. The second action is to find warm place. Detection of the heat let the tick know that the surface around it is the skin of a mammal. All these actions can be

[13)] This idea was first presented in Chapter 11 of Shiozawa (1990).

described in a form of quadruplet qSS′q′. Branching process of actions can also be formulated by this quadruplet. For example, when the tick fails to fall on a mammal, lack of heat dictates that the tick should go back to the tip of a bush branch again. This choice of actions which depend on the situation can be given as a pair of two quadruplets, with the same internal situation q (the state after the free fall) and the different S and ~S . Here S is the state in which the tick detects the heat whereas ~S is the state in which the tick fails to detect the heat for a suitable trial time.

Both of animal behavior and human behavior can be decomposed in the same way to a series of simple actions which can be represented in a form of quadruplet qSS′q′. Difference between human behavior and animal behavior is that human behavior is much more plastic in the sense that human behavior can be remolded into a different series of actions whereas animal behavior is much more stubborn in the sense that animal behavior is more often impossible to change. Despite these differences, there is a remarkable continuity between human behavior and animal behavior. We can easily imagine how an intelligent human behavior came into existence in the world. At the very beginning human behavior was not very intelligent and not very different from animal behavior. After a long history of experience, human being improved their behavior in an evolutionary manner. This process should have been helped by the mankind's high capacity of learning, adaptability, and by the use of language and sign systems and intelligence. But the essence of the process is the same as the case of animal's learning and acquisition of a new behavior.

Quadruplet formula can be a bridge that connects animal behavior and human behavior. This indicates that quadruplet formula is not only a convenient expression of a rule-based behavior but one that can show the nature and the structure of human economic behavior. Rule-based behavior can now be defined as behavior that is expressed by a set of quadruplets.

6.5 Mode of selection of behaviors

Let us come back to human behavior. If-then rule behavior and a series of these if-then rules do not require a high level of intelligence. However, this does not mean that the performance of this type of behavior is inferior to that of more sophisticated definitions.

The maximization of any type, say a maximization of expected utility, gives an instruction on how to behave, if it is possible to find the solution. As explained in Subsection 6.2, the obtained result does not assure that the solution is the best possible action in any substantive way. The solution of the maximization problem only means that it is the best one in a fictitious world of subjective estimates. A rule-based behavior, which is a result of a long history of evolutionary process, may produce much better results than the solution of the imaginary maximization problem.

The evolutionary process of human behavior is of course different from that of animals' behavior from various points of view. Animals have a behavior pattern that is proper to their species. Ethologists teach us many such species-specific behaviors. The most important of them is the mating behavior. Be them insects, birds, or mammals, male finds a female of the same species quite accurately. Birds of two different species sometimes resemble with each other so much that even a researcher has a difficulty to identify them at a first glance. However, birds can distinguish specific traits in one another and can choose an appropriate partner.

Some behaviors are repeated in a rigidly fixed pattern. In the egg-laying season a male three spined stickleback will attack male competitors of the same species. The sign stimulus is the red color of the fish formed objects. So sticklebacks attack any model-imitations with this trait, even they do not resemble stickleback at all.

Animals show a wide variety of behaviors, but they have only few options for each predetermined situation. If a specific stimulus or releaser is shown, animals often take a unique fixed behavior. In this sense, animals' pool of behaviors is poor. Many ingenuous behaviors have only been obtained through a long history of selection for many generations.

Humans show the same type of action patterns as animals do. The difference between humans and animals is that humans have a wide variety of possible patterns, which are taken at a specific situation. In this sense, humans have a broad range of patterns for them to select in any situation. Selection occurs mainly as learning. When an experience produces a bad result for a specific behavior, learning occurs very quickly, and a bad behavior is excluded from the pool of behaviors. This experience can be transmitted to other members of the society. So the behavioral evolution for humans occurs for an individual, or in one generation, whereas animal evolution requires many generations. If we use terms of biological evolution, behavioral evolution is phylogenetic for animals and ontogenetic for mankind. So the human behavioral evolution proceeds much more rapidly than that of animals.

Flexibility of behavior, creative imagination, memory, causal reasoning, and comparison of results are mankind's specific capabilities. With these characteristics, humans are able to invent new behavior, compare experiences, select a better pattern, and learn from the best practice. Even when rational activity in each behavior is not evident, human behavior is well organized and designed.

6.6 True levels of choice

In the neoclassical formulation, choices are made all at once. When a human being is endowed with an unlimited capacity for rational reasoning, he or she may produce good results. Using current and past information, humans can arrive at the best solution. This is the story supposed in the expected utility maximization model. However, humans live in a complex environment, and their rationality is limited. In this situation, choices made all at once do not produce good results. Humans know this does not work. In reality, choices are made on several levels.

Take the example of Subsection 6.3. In the given situation Q, action A was taken. What have we chosen in this case: action A or the rule Q ⇒ A? The action to be taken is the same. However, there is a difference in the level of choices. In the first case, action A was chosen from among all other alternative actions. In the second, one rule was chosen from among several.

In a real-life situation, the difference becomes much clearer. For example, an inventory control of an automobile parts shop is cited. If you were the shop keeper, you are requested to reduce two variables: the inventory and the risk to loose customers. These two objectives are usually contradictory. When you reduce the inventory, the possibility of selling out of an item increases, and customers may choose to buy the item elsewhere. It will increase the possibility to lose customers.

Suppose that, every Monday, parts are replenished from the factory after an order is given at the end of the previous week. On each weekend, the shopkeeper must determine, for each item, what quantity to hold at the beginning of the next week. This is an example of typical economic decision-making. The shopkeeper can make a prevision on the sales of each item and decide the best quantity for each item each weekend. In order to do this, the shopkeeper must know the probability distribution for each of the items. Even if a shopkeeper has sufficient data to determine these distributions, it requires a considerable amount of calculation. There is another method of controlling. The shopkeeper starts with choosing a random quantity for each item. This is a temporarily determined target. At each weekend, the shopkeeper orders so as to secure a temporal target for each item. When an item is sold out at mid-week, the shopkeeper increases the target of the item, by approximately 20 percent, for example. On the other hand, when an item remains for more than 5 weeks consecutively, the shopkeeper reduces the target of that item by 10 percent. At the beginning, this control method may not be very accurate. The shopkeeper may find himself sold out of some items and with too much remaining inventory of other items. However, as time passes, this method provides a plausible level of inventory, and the performance will improve. The best point of this control method is simplicity. It requires no statistics and no laborious calculation.

In the first method, the shopkeeper chooses the best inventory for each item and for each week. In the second method, the shopkeeper chooses the method. This method contains some parameters, and the shopkeeper must choose a good pair of parameters. When the parameters are given, the target inventory is calculated easily. So the real selection is the choice of parameters. The adjustment speed depends on the parameters. The choice of good parameters is a higher-level choice than the application of rules for controlling an inventory. It requires more time and wider experience than the simple inventory control.

The choice between different types of rules is sometimes more subtle. There may not be a readily best choice. Textbooks on inventory control do not compare different methods directly. The result may change for different situations and purposes. It is quite probable that several rules of control will continue to be employed simultaneously.

Evolutionists do not deny choices. The difference between evolutionists and neoclassical economists is that the latter has an obstinate tendency to suppose that people choose everything every time, whereas evolutionists think that there are several levels of choices and plausible levels are chosen for each situation.

7. Knowledge and behavior

Knowledge is not usually thought to be an economic factor. However, as W. Arthur Lewis (1955) has argued, knowledge is an important factor and a vital resource for the economic growth of any society. Friedrich von Hayek, reporting that the market is a system that enables knowledge of different people at different places to be coordinated, considered the use of knowledge as the most important element of economics. Evolutionary economists now think knowledge is the core topic of evolutionary economics.[14)]

Knowledge as a whole is a closely woven unity. But it can be decomposed into small units, each of which can be expressed in the form of a sentence. These units of knowledge can be transmitted from person to person through learning. Knowledge satisfies the 5 conditions given in Subsection 3.4, and therefore each unit of knowledge can be seen as a typical entity which evolves.

[14)] The importance of knowledge is now expressed by various economists. See Loasby (1976; 1991), Lackman (1986).

In Section 3 three categories of evolving entities are discussed: commodities, technologies and institutions. Each of these entities is closely linked to knowledge. A commodity embodies many kinds of knowledge: how and where to procure materials, how to produce the commodity with minimum cost, and how to promote it in face of many other competing commodities, and others. Technology is a set of guiding principles which organize elements into a system with specific functions. These guiding principles make an important part of human knowledge. Institutions are rules of the society. When they are memorized by the people as a part of knowledge, rules become socially effective. Even a delinquent considers the consequences of his or her delinquency. The accumulation of knowledge stimulates the evolution of commodities, technologies and institutions. In fact, the accumulation of knowledge is the engine of economic development and gives the human economy a very different feature of evolutionary process.

In the following, however, relations of knowledge to three other categories will not be investigated. We will concentrate ourselves on discussing the link between knowledge and behavior.

For more than 2,000 years, it has been believed that knowledge is connected to truth. A proposition is a statement which can in principle be determined whether it is true or false. In the traditional understanding, knowledge is a collection of true propositions.

This understanding of knowledge has been reinforced by various reasons. Philosophy and logics have a long history to regard the contents of true propositions as typical knowledge. Logics have been preoccupied with true propositions. Epistemology was the part of philosophy which argues how and by what title we can get true knowledge. Teaching at school also shows a strong tendency to tell that the knowledge is a collection of true propositions. Science is a systematic effort to reorganize various propositions and to search true ones. In these circumstances, it is rather natural that people believe that knowledge is a collection of true propositions.

However, this is only one half of the human knowledge. The other half of knowledge consists of statements that can be considered to be useful or not useful. These statements do not even take the form of a proposition. They can be a statement that tells what to do in which conditions. Contents of these statements are often called know-how, whereas contents of true propositions are simply called truth.

Gilbert Ryle (1949) was the first person to consider that knowledge is composed of two parts of different characters: knowing-that type of knowledge and knowing-how type of knowledge. In economics knowledge of knowing-how type is much more important, for it is this type of knowledge that mainly supports our behavior. Knowledge of this type takes a form of conditional directives: in such and such case, do this and that. These statements can be expressed in the form of if-then rules. For example, let us assume that the rule of conduct $Q \Rightarrow A$ is being considered. This rule is neither true nor false. The value of $Q \Rightarrow A$ is the usefulness of this rule when it is adopted as a rule of conduct. Logic is the science which examines knowledge of knowing-that type. Knowledge of knowing-how type has no such discipline. Investigation of this type of knowledge is not developed yet and stays in a very naive state. However, this does not mean that this type of knowledge is less important than the other. Indeed, human behavior is always coupled with this type of knowledge. Remind that behavior can be decomposed into a series of if-then rules or CD transformations. When knowledge is understood to be of this type, it is easy to see that knowledge and behavior are the face and back of the same coin.

Mankind possesses memory. Knowledge of all types is kept in the memory. In the early era of mankind, memory was only supported by the brain. After the inventions of letters, documents and libraries began to be used as extensions of memory. A large accumulation of knowledge became possible. Memory is a base that enables mankind to develop its economy in a cumulative way.

8. A breakthrough with a new tool

Many economists agree that the neoclassical economics has drowned into the stagnating stage. No breakthrough can be expected on the extension of the present research program. Alternative frameworks have been proposed many times but they could not replace neoclassical economics, because they could not produce research program which is as powerful and productive as neoclassical economics. The reason why neoclassical economics had became so productive was that it succeeded to incorporate mathematics as analytical tools. Using diagrams and calculations, it was easy for economists to analyze certain types of problems and obtain some results. But this productiveness there and then became the trap for neoclassical economics. Usefulness of mathematical formulae is connected to solvability of the formulated problems. Even if mathematics is a powerful tool, the situations that can be mathematically analyzed are rather limited. Equilibrium was an important exception. This was the main reason why neoclassical economics could not abandon equilibrium framework.

To propose a new theoretical framework is not sufficient for a coming breakthrough. It is necessary to present a new tool, which is as powerful as mathematics was for neoclassical economics and suitable for the new framework. In order to consider this problem, let us start to examine the present state of the art of economic science.

8.1 The state of the art of economic science

For more than 100 years, economics has been based on equilibrium and maximization. The main tool of analysis was mathematics. It started from the stage of counting the number of unknowns and the number of equations. Walras, in the 1870s, was satisfied to show that two numbers were equal. From the 1930s, a new era started, and more refined mathematics was introduced in order to show that the solutions really assume non-negative values. In the 1950s, Arrow and Debreu succeeded, using a generalized fixed-point theorem, in proving the existence of equilibrium under very wide assumptions. At this stage, the general equilibrium became mathematically perfect.

At first, there was a kind of euphoria. Many people hoped that theory and econometrics, with the aid of computers, would open a new road to a scientific and powerful economics. However, after the initial enthusiasm, strong criticism was made against the state of the art in the first half of the 1970s. The very framework of economics was attacked. The demand function presupposes that consumers are perfectly rational. The supply function presupposed that there are decreasing returns to scale to the producers. In reality, people have a very limited rational capacity, and most production firms operate with increasing returns to scale. This is a rather well-known result, and the anomaly of the economics was evident. Most economists know that many of the basic assumptions in economics are unrealistic. Reconstruction from the very bases of the framework was required. But most economists are reluctant to reconstruct the economic theory. Some economists claim that restructuring may require the loss of mathematics, which has been the main drive to economics for more than 100 years.

The state of the art of economics can be compared to that of physics at the end of the 19th Century. At that time, it seemed that classical physics was firmly established, and nobody imagined that physics needed a fundamental reformulation. But at the beginning of the 20th Century physics had to accept two biggest revolutions in the physical science i.e. the quantum theory of Max Plank and the relativity theory of Albert Einstein.

In the case of economic theory, at the beginning of the 21st Century, a renovation of the economic theory is needed. This necessity is more evident than it was for physics at the end of the 19th Century. Several important anomalies are observed at the very base of economic theory. It would be fair to ask why there has not been a paradigm change comparable to the one that occurred in the field of physics at the beginning of the 20th Century. It is not because there are no geniuses, such as Albert Einstein or Max Plank.

The history of economics can be divided into three periods. For the first 100 years, the economy has been investigated mainly through literal discourse. In the next 100 years, mathematics was the leading tool for the development of modern economics. It started with simple calculations of some partial differential coefficients. Now, a highly sophisticated mathematics is commonly used in different domains of economics. However, the power of mathematics is approaching a saturation point. No longer can people expect mathematics to fuel the further development of economics. It is now time march to a different drummer.

There are many interesting topics and phenomena we want to analyze. However, the lack of suitable tools now obstructs the further development of economics. Therefore, the problem can be set in an opposite way. The first step is to provide a new tool. With such a tool or a new method, the fields of analysis can be enlarged and theories will come afterwards. This aspirated tool may be multi-agent model analysis, or agent-based simulations and analysis.

8.2 The merits of multi-agent models

A multi-agent model is a type of computer model in which agent classes play an important role. Agents have their own rules of behavior and interact with each other through a certain rule of combinations.

The general equilibrium and partial equilibrium theories contain agents called producers and consumers. They are supposed to behave as theory dictates. In this broad sense, microeconomic models are multi-agent models. However, there is a big difference between microeconomic and multi-agent models. In the terminology of J. W. N. Watkins, microeconomic models are “algebraic.” A typical situation is shown by the Arrow and Debreu’s competitive equilibrium model. The production possibility sets are supposed to be closed and convex, but no specifics were given. However, the existence of equilibrium can be proved, thanks to a very general fixed-point theorem.

Multi-agent models are different. Each agent is defined to have a concrete set of behavior rules. In any given situation, the behavior of a particular agent can be determined. Multi-agent models are, in this sense, “numerical.” The behavior of any agent can be calculated numerically from a set of relevant conditions.

Multi-agent models have four distinguished merits.

Firstly, models can include a variety of different agents. In the abstract micro-economic models, such as in Arrow and Debreu’s equilibrium model, each agent can have different characters. However, in a detailed analysis, when, for example, there is a necessity to analyze the shift of equilibrium with the incremental variation of one variable, the agents are supposed to be identical. Without such simplifying assumptions, it will be extremely difficult to analyze mathematically what happens in the model. In a multi-agent model, the processes are computed numerically via computers. Different characteristics of agents do not hinder the calculation of the process. The difficulty is limited to the time required to input data for each agent. Therefore, the variety of agents does not cause problems.

Secondly, in the multi-agent models, the processes are defined in such a way that, at each step, agents determine their actions, and the results of these actions are reflected in the next step. This simple change in procedure can free people from the curse of equilibrium. In the multi-agent models, it is not necessary to be confined to the equilibrium situation. At each step, the appropriate action is determined, and a market-matching rule is used to determine the initial state of the next step. This step-by-step analysis was once recommended by the Swedish school economists, who called this method "period analysis". However, without personal computers, the analysis became too complicated, and period analysis did not produce a remarkable result. Now we have cheep and fast computing power. Ideas of period analysis can easily be incorporated into multi-agent model analysis.

Thirdly, a multi-agent model does not necessitate maximization or equilibrium. Positively, there is freedom from the traditional neoclassical framework. Some people are bewildered with the new possibility, for they can postulate any kind of behavior to the agents. Any type of behavior can easily be incorporated into the computer. The instructions in the computer are actually programed. Any behavior that requires an intractable calculation is automatically excluded.

Finally, a multi-agent model can incorporate the evolutions of behaviors. In Subsection 6.4, we reported that the most elementary forms of behavior can be given in the form of CD transformations. If codes C and D are specified by binary digits (0–1 vectors), CD transformation is nothing more than a classifier system. Just as J. H. Holland did with his idea of a genetic algorithm, it is not difficult to incorporate evolution in a multi-agent model.

As shown above, multi-agent models are astonishingly congenial to evolutionary economics. Analytical tools that contribute to evolutionary economics should satisfy the following five conditions:

(1) They can incorporate evolving entities into the model.
(2) Entities can undergo mutations.
(3) Entities can be replicated as a property of other agents.

(4) Interactions should be developed in a process.

(5) Selections and evolution can be incorporated.

A multi-agent model can easily satisfy these conditions. For the moment, there is no other tools that satisfy the five conditions. Evolutionary games and replicator dynamics satisfy some but not all of these conditions.

To summarize, multi-agent models provide a new powerful tool that extends far beyond the equilibrium framework. It is useful to analyze the process from an evolutionary perspective. Multi-agent models can be a trigger of shifting the economic paradign to a new era.

8.3 The case of the U-Mart project

In this Subsection, the U-Mart Project will be presented. This is a research project that includes a part of the multi-agent model analysis, but it also has different features with different aspects.

This project started with the name V-Mart in 1999. However, since there is a convenience store chain called V-Mart in the United States, the name of the project was changed to U-Mart. Economists and engineers were jointly involved in this project. Via their teamwork, a large-scale computer program has been developed. The system is articulated in two subsystems: a market server and a client server. It has also two versions by the mode of experiments: a network server and a stand-alone server. The market server receives bids from clients, determines prices, and executes clearing operations. The client server provides an interface for trades with a simple click on the computer screen.

A U-Mart is, in fact, a virtual futures market in which one can sell and buy a stock price index. The J30 index is used as a spot price. It is a stock price index, developed by the Mainichi Newspapers. For the moment there is no real futures market for the J30 index. At the end of the market term, the futures price is evaluated by the value of the J30 index. In the experiments we usually use real time series of the past J30 in order to avoid feeding arbitrary time series. In this way, the U-Mart market is a virtual market that has some grounding in the real economy.

One of the special features of the U-Mart is that, in this market, both human and machine agents (a program of trading actions) can participate on an equal footing. Several public competitions have already been organized, openly inviting people to submit a program. Usually, at each competition, from 10 to 20 people participate as human agents, as well as 50 or more machine agents. The total number of agents is, thus, on the order of 80 to 100. People are being invited to participate in the competition as if they were in a competitive game. The objective is to obtain at the end of the session the highest value of the money balance. Specialists of experimental economics criticize that there are no real incentives in this game. In competitions that have taken place, participants become excited and often want a second trial chance and we think that no such incentives are necessary.

A U-Mart can be used as an education opportunity. Many of the U-Mart members invited their students to participate in the game, first as human agents and second as machine agents. This gives them a good chance to write down a program that works in a situation similar to real life. We also distribute a U-Mart system freely upon subscription.

The obtained price movements are, in most cases, satisfactory. When the participants have no experience, the prices fluctuate roughly and abruptly. Many participants go bankrupt. In the next trial, participants became more cautious and try to avoid bankruptcy. The price fluctuation becomes more refined, and the values remain near the spot index value.[15)]

8.4 Possibilities of multi-agent simulations

A U-Mart played by machine agents alone is a typical example of multi-agent models. Many things can be done that were impossible to achieve with a mathematical analysis.

One such possibility is the observation of a micro-macro loop. A micro-macro loop is an important topic that is related to the very base of modern economic methodology.

Neoclassical economics assumes methodological individualism. After this methodology, an economy can be constructed from the behavior of individuals. The Arrow and Debreu model of a competitive economy is a good example. Given the consumer preference, producer technology, and ownership distributions of resources, equilibrium is defined in this construction. Equilibrium thus defined is thought to produce the present state of the economy. Schumpeter (1925) called this doctrine construction *ab ovo* (construction from an “egg” stage). Evolutionists have totally different images of how the present state of the economy is formed. All knowledge-supported entities, i.e., commodities, technology, institutions, and individual behavior, are results of past evolutionary processes. They are all path-dependent. Ownership distribution of resources is also a result of past economic processes that are, in turn, a result of close interaction of those entities. Evolving entities are a result of past selection processes, and what remains active at present influences the development of the economic process itself.

15) For the details of the U-Mart project, see http://u-mart.econ.kyoto-u.ac.jp/index-e.html.

The micro-macro loop is a causal relationship of evolving entities (micro=individual behaviors and knowledge) and the total economic process (macro=economy as a whole). If we observe the existence of micro-macro loops, methodological individualism is not sustainable at all. The refutation of methodological individualism does not imply that the methodological holism is acceptable. The latter must be abandoned as well. The concept of the micro-macro loop forces us to get away from the old dichotomy of individualism and holism.

The importance of a micro-macro loop is evident, but it has not received sufficient attention. The reason is clear. We were lacking methods for treating these types of causations. However, it is now expectable that the U-Mart will provide a concrete example of a micro-macro loop. An investment strategy of day traders is to extend a buy offer with a directed price that is one per cent higher and the same amount as a sell offer with a directed price that is one percent lower than the starting price of the day. If both of the offers are concluded, the trader gains a two percent margin minus the cost of the transaction. When the transaction cost is on the order of two percent, the above strategy produces nothing. If the cost comes down to one percent, the day traders have a chance to make money using the above strategy. This is only possible as long as the price fluctuation or volatility is sufficiently large that both of the proposed offers are satisfied with a high probability. However, this strategy is not valid constantly. When the traders increase their volume of trade, these trades will influence the price movement, and the volatility will be depressed. In multi-agent models, it is easy to achieve cases such as the ones given in these examples.

An institutional study is also possible. In the U-Mart case, board information can be disseminated in a different way, and the difference of behaviors and performances can be observed. These topics are usually called “microstructure of the market.” So far, only empirical studies have been under way. Multi-agent model simulation makes it possible to analyze, on an experimental base, the effects of micro-structural differences. It may be possible to produce a thin market intentionally in order to study the roles of market makers. This study may lead to a low-cost market management and design engineering of thin financial markets.

8.5 Some theoretical problems and difficulties to overcome

Multi-agent model experiments, as well as other experimental studies, such as the U-Mart with human agents, have a common problem. Results can be obtained whenever experiments are conducted. They may yield some knowledge. However, it will be necessary to determine what knowledge is substantial. It will also be necessary to determine how such knowledge can be obtained. In most multi-agent models, there is a high degree of freedom in choosing parameters. If the result remains to show a property that is similar to another, it will be possible to conclude that differences of parameters have little influence on the result. However, this would be true in a fortunate case only.

Similar problems are faced when experimental science began. In the case of experiments, there are standard sets of criteria to determine whether a claimed observation is correct. An affirmative test in second experiments is one such criterion. In the case of computer simulations, there are no standard procedures to confirm that an observed result has been established as firm knowledge.

At this point, however, there is reason for optimism. Agent-based simulations and analysis are the third mode of scientific research, which is just at the beginning stage. The first mode was theoretical reasoning. It appeared somewhere in classic Greece. With the aid of logics and mathematics, this research mode became well established. In medieval Europe, this mode of reasoning fell down to a speculation without any relevance to reality. Similarity to the present state of modern economics is observed. A new mode of scientific research was then introduced about a millennium later. It was an experimental method. Initially, the experimental method was closely associated with alchemy and occult science. There were many difficulties associated with the experimental method; however, it ultimately became the primary method for research.

Multi-agent model experiments are a new mode of scientific research. It is natural that this newly developed method would have many problems and deficiencies. It is necessary to develop new fields of computational experiments. At the same time, it is also necessary to examine reflexively the nature of knowledge obtained from such computer experiments.

We are at a turning point for the economics. With the development of multi-agent model experiments, various kinds of knowledge can be accumulated that would be difficult to obtain with pure reasoning. The limits of mathematical methods will become clearer. Multi-agent models will liberate economists from the traditional confines of the equilibrium and maximization. The third mode of scientific research will be recognized as a necessary tool of economics. All these changes will contribute to the reconstruction of economics on a new basis. At that time, a real paradigm shift will occur, and economic science will take a new form, quite different from the present one, and certainly very close to the evolutionist's perspective and frame.

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