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A Schumpeterian Innovation System in Knowledge Capitalism
- System Dynamics with STELLA -

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Abstract

The purpose of this research is how to locate 'knowledge' in the theoretical and institutional framework analyzing modern capitalism and how to analyze the interactions among different kinds of knowledge and their possessors. At first, I show three perspectives of this research. The first is that modern capitalism is the knowledge-based economy. The second is that it is necessary to understand innovation as a system. I integrate those perspectives in my framework of the Marxian-Schumpeterian diagram of economic evolution and consider it in terms of the framework of national innovation systems. Then, I construct the 'knowledge version' Marxian-Schumpeterian diagram as now analytical framework. I investigate a useful method of analyzing knowledge capitalism. I propose my analytical framework for using an analytical tool of system dynamics modelling. Thirdly, I put my system dynamics model in practice with STELLA, so this part is the most essential part of my research. In particular, STELLA is available to express the interactions of heterogeneous agents with different knowledge in one industrial sector and among related industrial sectors. In conclusion, I summarize this research in three points; (1) In this research, I examined how to analyze modern knowledge capitalism with mainly two considerations. The bases of my approach should be required a process

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thinking of knowledge capitalism which maintains the logic of industrial capitalism and includes the interactions through knowledge. Here, the core subject would be how to relate non-market or institutional dimensions to knowledge reproduction processes. (2) I conclude that a more suitable method to analyze the knowledge interacting system or knowledge network system is the system dynamics analysis. Finally, for the purpose of using the analytical tool of system dynamics, I propose the 'knowledge edition' Marx-Schumpeter diagram. (3) Moreover, I put above now framework into practice with STELLA. I will bring out some implications from this system dynamics analysis, especially concerning how to design the allocation of efficient institutions in the national innovation system and how to change the economic outcomes according to the changes of the ways of interactions among heterogeneous agents with different knowledge.

Keywords: national innovation systems, Schumpeter hypotheses, knowledge capitalism, system dynamics, Neo-Schumpeterian economics

JEL Codes: B52, O32, D85

1. Introduction

The purpose of this research is how to locate 'knowledge' in the theoretical and institutional framework analyzing modern capitalism and how to analyze the interactions among different kinds of knowledge and their possessors. This proceeding is constructed mainly three parts.

The first part is the backgrounds and motivations of this research. This research is based on two perspectives. The first is that modern capitalism is the knowledge-based economy, so that we could say that modern capitalism is knowledge capitalism. This perspective is inspired by the idea of "restless capitalism" by J. S. Metcalfe (Metcalfe 2001; Metcalfe 2002; Metcalfe 2009; Metcalfe and Foster 2010; Metcalfe and Ramlogan 2015). In a next section, I identified some distinctions of knowledge capitalism through comparing with industrial capitalism, especially on the relationships between the labour and knowledge and between the capitalist reproduction process and the knowledge. The second perspective is that it is necessary to understand innovation as a complex network system in which various heterogeneous agents interact with each other. In these days, this framework of understanding has been called "National Innovation Systems (or "National Systems of Innovation)." In my previous paper, I investigated it and suggested the Marxian-Schumpeterian diagram on economic evolution. In this paper, I will present it in more detail and position it in the framework of "National Innovation Systems (NIS)." After that, I will construct the 'knowledge version' of Marxian-Schumpeterian diagram as an analytical framework of this research. I think this framework is expected to be a basis for the system dynamics model with STELLA.

The second part is a research of analytical methods of knowledge capitalism. I will propose my analytical framework for using system dynamics (SD) mainly through considering discussions of the recent Neo-Schumpeterian economics, on which I mainly depend in this paper are contributions on the economic complexity by Antonelli (2011), and the recent Post-Keynesian approach on NIS by Courvisanos (2012), and the critical examination on modern "new growth theories" which contain the endogenous growth model by Paul Romer and the Schumpeterian growth model by Aghion and Howitt (1992). Furthermore, I also examine an econometric analysis using a knowledge production function by Pakes and Griliches (1987). In this part, I will also consider the recent discussions of Aghion et al. (2015), because I think they have shifted the direction of research from their past paper in 1992 and their recent researches are moving in close to the awareness of the issues of neo-Schumpeterian economics.

At the third part, I will put my system dynamics model in practice with STELLA, so this part is the most essential part in this paper. Through above examinations of a Schumpeterian innovation

system, I will reach a suggestion that the most possible analytical method should be system dynamics. In particular, STELLA is available to express the interactions of heterogeneous agents with different knowledge in one industrial sector and among related industrial sectors.

The rest of the paper is organized as follows. In section 2, I consider a definition and some characteristics of knowledge capitalism. In section 3, I examine a relationship among NIS and Schumpeterian hypotheses and our Marxian-Schumpeterian diagram. In section 4, I provide critical reviews on neoclassical new growth theory and its econometric analyses. In section 5, I construct a SD model of knowledge version Schumpeterian Innovation System and practice it with STELLA. Finally, I provide a brief summary and potential future research aspects.

2. What is Knowledge Capitalism?

2.1 Two Backgrounds

One background of this research is that the weight of knowledge in modern capitalistic economy have been more and more increasing. As one of the recent tendencies of research in JSPE (Japan Society of Political Economy), the discussions on "information capitalism" or "knowledge capitalism" have been developed. For example, one opinion of those is that "information capitalism is the modern capitalist system which is sustained by 'knowledge labour'. So to speak, it is no more than a capitalistic production system completing the dependence on a physical dimension. Moreover, it is located on the continuous extension of industrial capitalism which capital accumulation operate as a major pillar of the social reproduction systems." (Handa 2007) Handa emphasizes that relations of production in industrial capitalism, which have been an essence of capitalism, remain unchanged. Thus, information and knowledge are no more than additional factors to industrial capitalism. The other opinion is that "an actual capitalist system contains not only commercial companies but also nonprofit organizations (NPO), families and governments. Moreover, it is a complex system which contains markets, states and local communities as economic coordinating institutions." (Nishibe 2011; 151) A meaning of 'internalization' is that a history of modern capitalism is a self-organizing process integrating non-market domains toward commercialization by market domains. This tendency is applied not only to a labour power commodity, but also to information and knowledge. Then, it is necessary to consider how to relate information and knowledge to the inner factors of capitalism under firm capitalistic conditions that 'capitalism is an economic system which capitalists purchase labour force commodities to produce own commodities for the purpose of gaining profits'.

The other background is related to an issue of a growing wealth gap in modern capitalistic economies proposed by Thomas Piketty. He mentioned the role of knowledge in a society with wide disparities of wealth as follows: "… the principal mechanism for convergence at the international as well as the domestic level is the diffusion of knowledge. … it is often hastened by international openness and trade. Above all, knowledge diffusion depends on a country's ability to mobilize financing as well as institutions that encourage large-scale investment in education and training of the population while guaranteeing a stable legal framework that various economic actors can reliably count on." (Piketty 2014; chap. 1). This quotation explains the necessity of institutional design for making efficient use of knowledge. Moreover, he said "… modern growth, which is based on the growth of productivity and the diffusion of knowledge, has made it possible to avoid the apocalypse predicted by Marx and to balance the process of capital accumulation. But it has not altered the deep structures of capital – or at any rate has not truly reduced the macroeconomic importance of capital relative to labor." (ibid; chap. 6). This means that the 'essence' of capitalist economy does not change, although there has changed qualitatively, and the capital-labour relationship is still important. Here, we will be able to understand that examining the role of knowledge is a research topic that cannot be avoid and passed by in modern capitalism.

2.2 Historical Positioning of Modern Knowledge Capitalism

Long Waves	Core Technologies	Installation*	Turning Point*	Development*
		Upswing**		Downswing**
1st	Water-powered mechanization	1771-90s	1793-97	1798-1829
		1780s-1815		1815-1848
2nd	Steam-powered mechanization, Railways	1829-40s	1848-50	1850-73
		1848-1873		1873-1895
3rd	Electrification, Steel, Heavy engineering	1875-93	1893-95	1895-1918
		1895-1918		1918-1940
4th	Motorization, Oil, Mass production system	1908-29	1929-43	1943-74
		1941-1973		1973-
5th	Computerization, ICT	1971-2001	2001-	-----
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Sources: Perez (2002), p. 57, *Figure 5.2*, Freeman and Louçã (2001), p. 141, *Table II.1*

*: divided periods of one long wave by Perez (2002). "Turning Point" means a period when previous institutions are reorganized for subsequent development.

**: divided periods of one wave by Freeman et al. (2001)

***Table 1*: Division of Long Waves as Techno-economic Paradigms**

The long-run development process of capitalism is marked off into several long waves. Each Kondratieff's long wave is an about 60-years cycle. A benchmark of dividing into each wave is conversion of its core technology. In Neo-Schumpeterian economics, it has been discussed as so-called "technological trajectories," "technological paradigms," "techno-economic paradigms." According to Perez (2002) and Freeman and Louçã (2001), modern capitalist economy is considered in the fifth long wave which is characterized by ICT as a core technology (see ***Table 1***). Although we can point out the differences between above two works, they are in common with the location of a present stage of capitalism which is in the 5th long wave in which the core technology is ICT.

2.3 Information and Knowledge

I think we should identify the difference between knowledge and information. According to ***Fig. 1***, knowledge is more valuable and more meaningful than information, because knowledge is shaped by means of related information to an individual specific context. The context is essential for taking information to good account. Thus the contextualized information is understood and accumulated within an organization and its agents. In economics, the characteristics of knowledge is often explained as the same of public goods, that is, non-rivalrous and non-excludable. Knowledge has, however, the additional specific features, that is, consistency and absorbability (Burton-Jones 1999). The former means that knowledge cannot be easily systematized and clarified. For example, custom and convention which have been followed cannot be easily thrown away. While the latter means that knowledge facilitates recipients' understanding. Therefore, more advanced their understandings, common knowledge is constructed more easily. In this sense, knowledge is inseparably related to human beings and organizations so that it cannot be considered as a physical good or a commodity just like information.

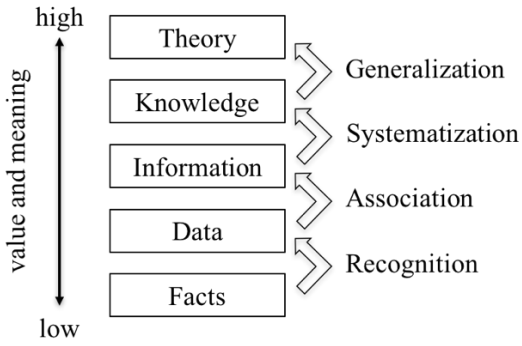

***Fig. 1*: Information and Knowledge**

If the contextualized information shapes the knowledge, each knowledge is different according to its context. Moreover, if the organizational context is changed, the agents' understandings within the organization is fluctuated. It is the SECI model (see ***Fig. 2***) that intuitively explains a spiral fluctuation of the organizational knowledge[2]. In the background of this model, it is assumed three key words: human, dynamic, and social. Then, a definition of knowledge is provided as "a human, dynamic and social process of justifying personal belief towards the truth." (Takeuchi 2013; 68) Although this model has been referred mainly in the research area of the organizational management, I think it will be able to apply to my Schumpeterian innovation system.

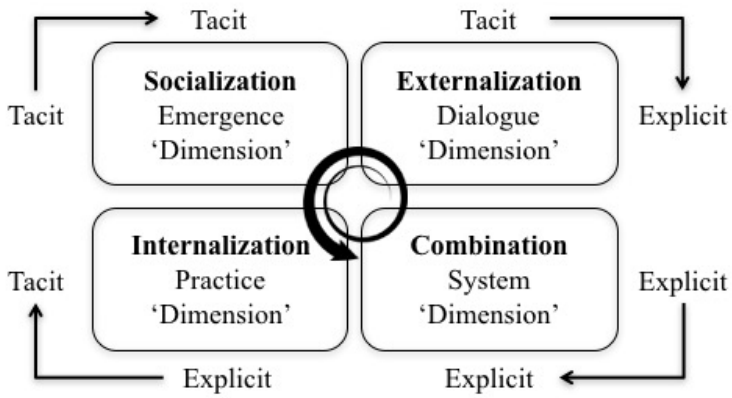

***Fig. 2*: The SECI Model**

In this model, the organizational knowledge contains two different types of knowledge: "explicit knowledge" and "tacit knowledge,[3]" and four mechanisms which convert two types of knowledge are functioning in spiral through time within a network of individual activities. The first phase of "socialization" is characterized as a process of sharing and creating tacit knowledge through direct experience at the individual level. Secondly, "externalization" is a process of articulating tacit knowledge through dialogue and reflection at the level of a group in the organization. It can spread more easily through the organization, however, because tacit knowledge can be virtually impossible

[2] Detail explanations are provided by Nonaka and Takeuchi (1995), Nonaka et al. (2008), and Takeuchi (2013).

[3] As another classification of knowledge, there is four kinds of knowledge suggested by OECD (1996): "Know-what," "Know-why," "Know-how," and "Know-who." "Know-what" refers to knowledge about "facts." "Know-why" refers to scientific knowledge of the principles and laws of nature. "Know-how" refers to skills or the capability to do something. "Know-who" involves the information of special social relationships which make it possible to get access to experts and use their knowledge efficiently. Therefore, the first and second seem to be related to explicit knowledge, and the latter two seem to be related to tacit knowledge (OECD 1996: 12).

to codify, the extent of this knowledge conversion mechanism is debatable. Thirdly, 'combination' is a process of systemizing and applying explicit knowledge and information. The last stage 'internalization' means that as explicit sources are used and learned, new tacit knowledge is acquired through practicing explicit knowledge.

Although this model seems to have a multiplicity of uses because it represents the interaction of intra-organizational knowledge, the reproduction process of knowledge and the fluctuation of knowledge, it seems difficult to understand or distinguish accurately between individual workers' knowledge and organizational collective knowledge. Especially, a transformation 'from explicit knowledge to tacit knowledge' and 'from tacit knowledge to tacit knowledge' seems difficult to understand. Then, researchers supporting the SECI model have insisted a necessity for the institutional framework to induce a transformation from tacit knowledge to explicit knowledge and have suggested a specific concept of "ba," which is translated in English as place, space, or field. Ba refers to the context in which human beings interact with each other under the specific institutional framework. I assume that the concept of ba should be usefully considered for constructing Schumpeter innovation system.

2.4 Restless Capitalism

The idea of 'restless capitalism' has been proposed by J. S. Metcalfe. Since Metcalfe (2001), this idea has been discussed in Metcalfe (2002), Metcalfe and Ramlogan (2005), Ramlogan and Metcalfe (2006), Metcalfe (2009), and Metcalfe and Foster (2010), and so on. He has started from epistemological and methodological consideration and has been trying to propose an original economic framework which is different from organization theories and knowledge theories. The main message of this concept is that 'capitalism is restless because knowledge is restless'. I would be able to point out its inclusive features as (1) an overall framework which contains the knowledge-base and the institutional structure, (2) the role of rules as a constraint of behaviour and/or as a facilitation of new behaviour, (3) coevolution between market dimensions and non-market dimensions, and (4) endogenous growth involved knowledge growth in the system.

Knowledge capitalism would be related to the fundamental characteristics of capitalism which have discussed in past Marxian economics or political economy. In Marxian economics, productivity is meant the human beings' capacity of controlling nature. Two of some conditions which make a maximum of an upward tendency of productivity may construct new relations of production (Okishio 1993; Chap. 1). One is the expansion of the human activities to control nature, the other is the extension of the human capacity to process information. A global diffusion of information and knowledge may

develop above two conditions through the ICT networks. In recent discussion, some implications about effects of ICT diffusion are pointed out (Foray 2000; 85-6). First, the costs of coding brief information have been reduced by the progress of printing technology. Second, it has been possible to coding more complicated information by developing programing languages and increasing modeling capacities. Third, the economic value of coding has been increased because coded knowledge has easily circulated by new electronic communication infrastructures.

I want to clarify current discussions on the restless capitalism. The word of 'restless' is meant the knowledge is restless. Knowledge would also be reproduced through the engineering reproduction process. The meaning of 'capitalism' is meant the 'logic of capital' has been maintained in knowledge capitalism. However, new factors should be added in the original logic of capital, that are, new relations of production which physical labour and brain labour are recombined through knowledge, and the roles of 'new entrepreneurs' who take on the responsibility of giving a meaning to knowledge.

Metcalfe suggested on the method of analysis of the restless capitalism. He seemed difficult to analyze above characteristics by using a traditional neoclassical production function added a knowledge variable as a new input. Therefore, it would be only quantifiable knowledge that we can handle with a knowledge production function. So, we need a framework which is considered knowledge interactions. It will be necessary for our framework to be able to deal with a market dimension (quantifiable) and a non-market or institutional dimension (non-quantifiable) simultaneously.

3. Schumpeterian Innovation System

3.1 Knowledge, Technology, and Labour: Referring the History of Economic Thought

Above-mentioned the third forecast of the post-industrialization discussions seems to be related more or less to adjustability and constancy of the labour relation and the labour process. Concerning that, two outstanding changes of the standardization of operations and the fattening of an organization have been proceeded in knowledge capitalism. In other words, the outsourcing of knowledge and the internalizing of knowledge have been developed.

In political economy, Nakaoka (1970) observed and considered in great detail about the labour process within the capitalist factory. According to Nakaoka's work, the labour process contains two different aspects, that is, one aspect is the process to view oneself objectively which one transfers own laboring capacity to labour products, the other is the process to accumulate knowledge and experience

which one absorbs knowledge and experiences from the objects and accumulates those as own laboring capacity. The latter is essential for the examination of the role of knowledge on the labour process. In knowledge capitalism, there is a possibility that physical work and brain work may be recombined and the laboring classes may commit to decision making on production and management.

Looking back the history of economic thoughts on the economics of innovation connected with knowledge, I will especially refer to next three trends: (1) Smithian theory of the division of labour, (2) Marxian theory of the labour-saving technical change, and (3) Schumpeterian theory of innovation[4].

The first trend of the Smithian theory of the division of labour had been developed toward the so-called demand-pull hypothesis by N. Kaldor and J. Schmookler. Adam Smith mentioned the relationship among technology, labour, and knowledge as follows.

> "All the improvements in machinery, however, have by no means been the inventions of those who had occasion to use the machines. Many improvements have been made by the ingenuity of the makers of the machines, when to make them became the business of a peculiar trade; and some by that of those who are called philosophers, or men of speculation, … Each individual becomes more expert in his own peculiar branch, more work is done upon the whole, and the quantity of science is considerably increased by it." (Smith 1791; chap. 1)

Smith considered the technological knowledge had been created through the learning-by-doing. Moreover, he also considered the technological knowledge had been created through building expert systems. I think we would derive some implications from Smith that the source of wealth is the human individual and practical knowledge embodied as 'expertise, skill and judgement'. These are required for the 'trivial inventions'. Furthermore, the outside invention of machinery within factory division of labour is a product of objective conditions rather than a result of talents and capacities of experts (Nishibe 2011).

The Second trend of the Marxian theory of labour-saving technical progress had been developed toward the theory of induced technical progress by J. R. Hicks and W. Fellner. Marx's innovation theory was the labour-saving process innovation on the whole, which induced innovation making prices of production factors change. A capitalist class was impelled by the decline of profitability through the competitive mechanism. On the other hand, Marx mentioned the relationship between technological change and the nature of labour.

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[4] See Cristiano Antonelli's paper "The economic complexity of technological change: knowledge interaction and path dependence" in Antonelli (2011). He also contained the other fourth trend of Marshallian theory of partial equilibrium and externality.

> "A characteristic feature is, that, even down into the eighteenth century, the difficult trades were called "mysteries" (mystères); into their secrets none but those duly initiated could penetrate. Modern Industry rent the veil that concealed from men their own social process of production into so many riddles, not only to outsiders, but even to the initiated." (Marx 1906; 532)

A historical technological change is coordinated with a shift of the nature of labour from craftsmen' skills and abilities, which mean physical abilities of workers, to machinery, which scientific or engineering logics of combination. In another aspect, it seems to be transition from 'social needs' to 'economic needs'. Therefore, building social innovation capacities to absorb outcomes of scientific knowledge seems to be required (Rosenberg 1976; Chap. 7).

Concerning the third trend of the Schumpeterian theory of innovation, it is needless to say that J. A. Schumpeter is one of the forefathers of innovation economics. Although he had not mentioned directly on the role of knowledge in his works, in the 7th chapter of the German first edition of *The Theory of Economic Development* (1912), he referred to a role of knowledge in his innovation theory in fragments.

> "For the other part, of course, the stock of technical knowledge increases independently and this would be the same in a static economy. Yet, inasmuch as in a static economy new innovations could find applications, the fact of their presence would only be the incentive for development, offering opportunities to new enterprises." (Schumpeter 2002; 102)

> "It is the conception that there is an independent element in technical and organizational progress, which carries its law of development in itself and mainly rests on the progress of our knowledge. Hence, the center of gravity is formed by that optimal combination which reflects the current state of our knowledge The particular combinations form clusters around this center of gravity There is an automatic tendency towards the center of gravity." (ibid; 103)

Especially, in the second citation, Schumpeter mentions knowledge as an endogenous factor of technological and organizational development, and the level of knowledge in each period regulates a direction and degree of development.

Modern evolutionary economics, especially Neo-Schumpeterian economics, has been focusing on the process of selection and diffusion regarding new technologies. However, it has not explained the mechanism on the emergence of new technological knowledge (Antonelli 2011; 9). Antonelli said that current evolutionary economists have not paid attention to two latter Schumpeter's remarkable contributions both published in *Journal of Economic History* in 1947; "Theoretical Problems of Economic Growth," (Vol. 7, 1-9) and "The Creative Response in Economic History," (Vol. 7, 149-59). Antonelli focused on the interactions of entrepreneurs' adaptive reactions and creative reactions to innovation and pointed out that new technological knowledge is the result of intentional activities based on four independent complemented inputs (ibid; 29): "Learning," "Search and development," "Access to tacit external knowledge," "Access to external explicit knowledge." In his framework, an organization seems to be an integrator of the organizational knowledge. In addition to that, he mentioned that the organizational collective knowledge was not replaced at once, because of operations of 'inertia' against the creative response.

3.2 Marxian-Schumpeterian Diagram on Economic Evolution

Innovation emerges within a whole economic system which contains various internal factors. I have discussed previous articles on the Marxian-Schumpeterian economic evolution. Although a main internal factor for Marx and Schumpeter was endogenous technological changes, on one hand, Marx focused on contradictions between the development of productivity and the relations of production, on the other hand, Schumpeter focused on new combinations (or creative destructions) by individual entrepreneurs. In other words, as to the source of economic evolution, Marx considered it a revolutionary change in the substructure and Schumpeter considered a discontinuous change in the superstructure. Anyway, their common idea of economic evolution is characterized by the three specific factors: dynamics of the process, historical dependency, and self-transformational process (Witt 2002; 10).

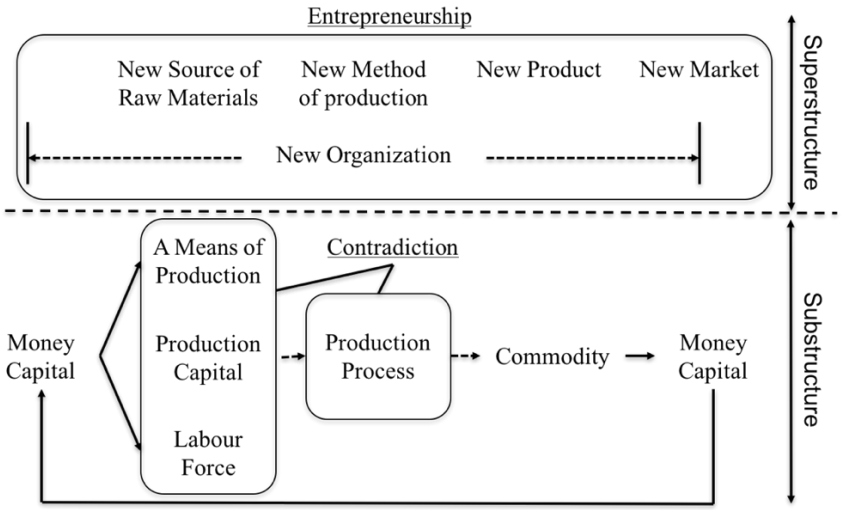


***Fig. 3*: The Marxian-Schumpeterian Diagram of Economic Evolution**

I have described this endogenous economic evolution in one figure (see ***Fig. 3***). I called it the "Marxian-Schumpeterian diagram." This diagram has a strong point that Schumpeter's five forms of new combination economic can be located in the framework of Marx's capitalist reproduction process[5]. In this paper, I suggest to integrate knowledge into this diagram in a framework of national economic system rather than within one firm as the SECI model.

3.3 National Innovation Systems

In modern Neo-Schumpeterian Economics or the economics of innovation, I think "National Innovation Systems (NIS)" has been confirmed as one of analytical frameworks for studying innovative processes since the latter half of 1980s. NIS have been defined in various ways as same as a definition of institution. According to Fagerberg and Sapprasert (2011), the early representative three contributions of NIS framework are Freeman (1987), Nelson (1993), and Lundvall (2010) which was first published in 1992. In each contribution, NIS was defined as follows[6].

> "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies." (Freeman 1987; Introduction and Summary)

[5] I think this diagram will be supported by H. D. Kurz. He said "Marx's account of the way capitalism develops comprises practically all the items contained in Schumpeter's list and considers innovation as a major weapon in the competitive struggle." (Kurz 2012; 69)

[6] However, on the other hand, according to Godin (2009), he pointed out that the contributions by OECD had been proposed since 1960s.

> "a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge and that a national system encompasses elements relationships, either located within or rooted inside the borders of a nation state." (Lundvall 2010 [1992]; 2)

> "a set of institutions whose interactions determine the innovative performance, in the sense above [a well-articulated and verified analytic framework linking institutional arrangements to technological and economic performance], of national firms." (Nelson 1993; 4, My square bracket.)

Moreover, Fagerberg and Sapprasert mentioned that "The inspiration for this [the researchers in IKE group[7] used a 'system' approach to the study of the national economy already in the 1970s], as is well documented … was clearly not the environment at the OECD but heterodox economic analyses inspired by the works of Karl Marx (who arguably had a system approach). In fact, the influence of Marxian thinking on advances in innovation theory revealed here is by no means unique." Consequently, OECD's contributions since 1960s and those by researchers of the heterodox economics seem to integrated via Bengt-Åke Lundvall. However, a quite difficult problem of how to measure knowledge, which OECD has investigated until now, has not been solved yet.

Among above three landmark works, for Japanese like us, Freeman (1987) would be the most familiar consideration. Freeman suggested the idea of NIS through considering an experience in Japanese rapid technological catch-up process after World War II. Japanese original characteristics was summarized in four points:

1. The role of the MITI (the Ministry of International Trade and Industry)[8]
2. The role of corporate R&D strategies related to imported technologies and 'disassembling engineering'
3. The role of social innovation which means human capital and the organization of work related to education and training
4. The role of a conglomerate structure of the industries.

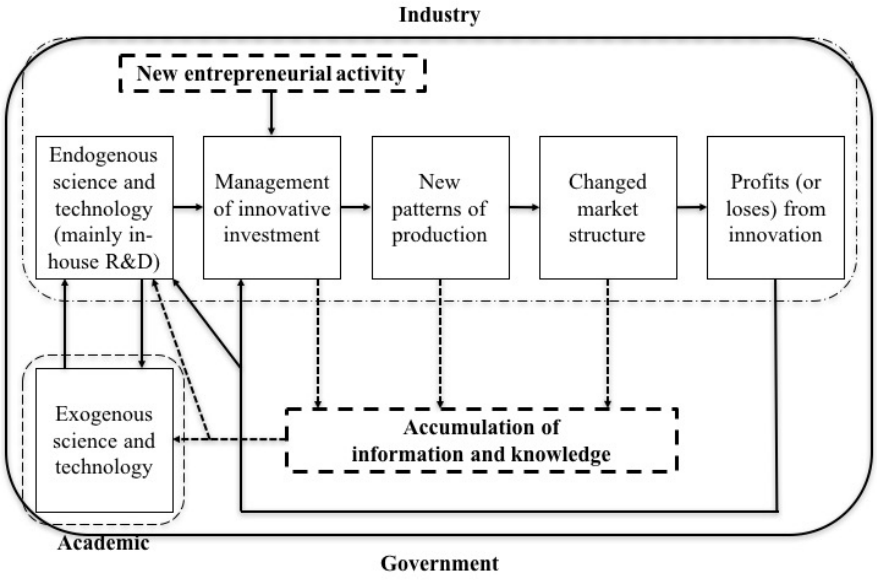
[7] The IKE group (literally the 'International Competitiveness Group') was started in 1977 at the newly founded Aalborg University Center in Northern Jutland in Denmark with Lundvall as the leading figure (Fagerberg and Sapprasert 2011; 673).

[8] The Ministry of Economy, Trade and Industry (METI) as it is known today since 2001.

Analizing output indexes on science and technology, Freeman concluded that the way of utilization of resources in Japan was more efficient than other advanced countries then because of then Japanese original institutional and social framework. Freeman's contribution has given valuable suggestions to subsequent discussions of NIS. Starting from investigation of Freeman (1987), Soete et al. (2009) derived four essential factors for the functioning of NIS: the investment of the country in social and human capital; the search capacity of a country or region; geographical proximity which relates the regional clustering of industrial activities; the demand factors that influence the take-up of innovations and hence the expected profitability on the part of the innovator which relate to the 'absorptive capacities' of consumers and more broadly national citizens (ibid; 21-23).

3.4 NIS and Schumpeterian Economics

I think the prominent source of NIS will be so-called Schumpeterian hypotheses. 'Schumpeter Mark I' and 'Schumpeter Mark II' have been discussed by respectively referring to Schumpeter's early work of *The Theory of Economic Development* (1912) and his later work of *Capitalism, Socialism and Democracy* (1943)[9]. After that, examinations on the Schumpeterian hypothesis have been developed and a new 'Schumpeter Mark III' has been proposed by K. Imai (1989), which was reflected the actual change towards knowledge capitalism. Here I suggest ***Fig. 4*** as an illustration of the combination 'Schumpeter Mark III' and NIS.



[9] See Freeman et al. (1982), *Fig. 2.3* and *Fig. 2.4* in Chap. 2.

Source: Imai (1989), Chap. 5.

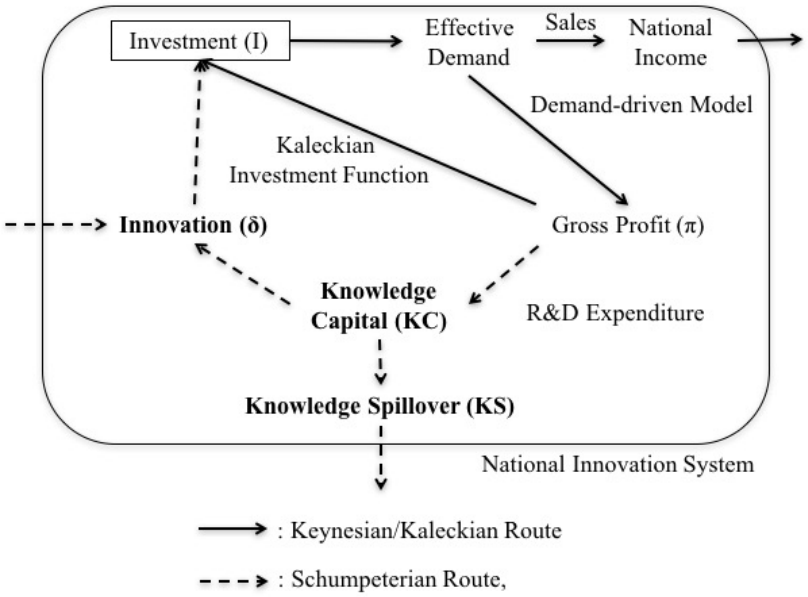
***Fig. 4*: Schumpeter Mark III and NIS**

In this figure, "New entrepreneurial activity" and "Accumulation of information and knowledge" (internalization of knowledge) are additional new factors. The former is reflected the transition of the agents of innovation from an individual entrepreneur, an organization of R&D to a new individual entrepreneur. The last new individual seems to be a manager of internal and external knowledge. The latter, I think, means a joint control of flow and/or stock of knowledge through a network mechanism[10].

Although, on one hand, Dolfsma and van der Velde (2014) also considered the possibility of formulating Schumpeter Mark III, their approach was aimed to examine a core agent of recent innovative activities. Then, they mentioned that "rather than the Schumpeter Mark I or the Schumpeter Mark II perspectives which point to entrepreneurial firms and large firms as sources of innovation, we, thus, suggest a Schumpeter Mark III position where established small firms are seen as a source of industry innovativeness." There is a methodological difference between my analysis and their analysis, but our interpretation of Schumpeter Mark III will be able to represent by using their expression that Schumpeter Mark III means the 'creative combination' of knowledge.

On the other hand, in Post-Keynesian economics, Courvisanos (2012) tried to integrate the Keynesian macroeconomic framework into the Schumpeterian theory of economic development as an innovative process within one NIS framework (see ***Fig. 5***).

[10] On this networking perspective, some recent discussions have been developed. For example, the "Knowledge-sharing Approach" and the "Resource-based View." The former focuses on the dispersion of the knowledge formation process into a R&D sector and an education sector, and discussed the systematized knowledge creation. The latter considered a firm as an aggregate of tangible and intangible assets within the system and focused on the capabilities of the organization. See Penrose (2009), Langlois (2007), Teece (2010), Mathews (2002).



Source: Courvisanos (2012), p. 75.

***Fig. 5*: Keynesian and Schumpeterian Integration in NIS**

I agree this attempt because I think it has great potential for modeling the NIS framework. I think the points of integration is in an investment on the knowledge capital stock. In this framework, two variables of 'gross profit (π)' and 'innovation (δ)' affect investment (I). A level of δ is decided by a function of the knowledge capital (KC) and the knowledge spillover (KS). KC is expressed by a combination of following two factors; (1) the human capital (L) which is the actual epistemological learning capacity and (2) the technological factor (RD) which it is formed potentially through R&D investment. Here, KS is assumed the general-purpose technologies as non-rivalrous and non-excludable public goods. Courvisanos formulated an investment function in general as follows.

$$\delta = f(L, RD, KS) \text{ and } I = g(\pi, \delta)$$

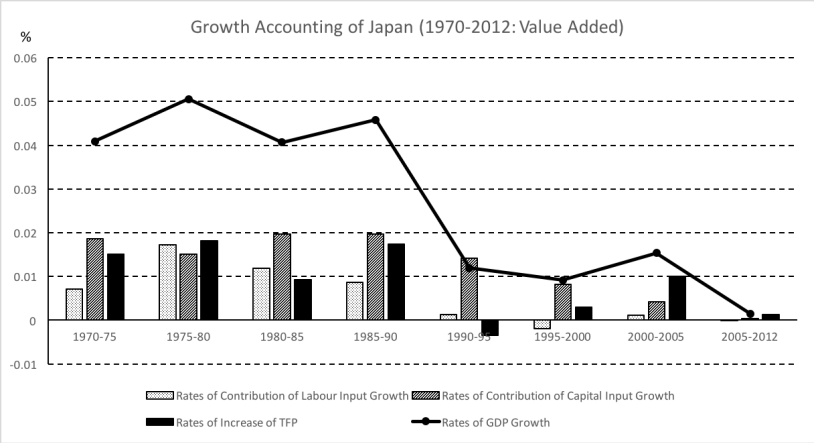
On these formulations of innovation and investment, I would point some ambiguous points. The first is that what is assumed as KC. It seemed KC to be only general purpose technologies. The second is that whether we can express KS quantitatively. I think this framework itself has an outstanding potentiality, but details should be more examined in the future.

4. The New Growth Theory and Econometric Analyses on Knowlege

4.1 Growth Accounting and Intangible Assets Data

In this section, compared with our NIS approach, I will examine whether measuring knowledge is possible or not, and whether past theoretical and statistical approaches are appropriate or not.

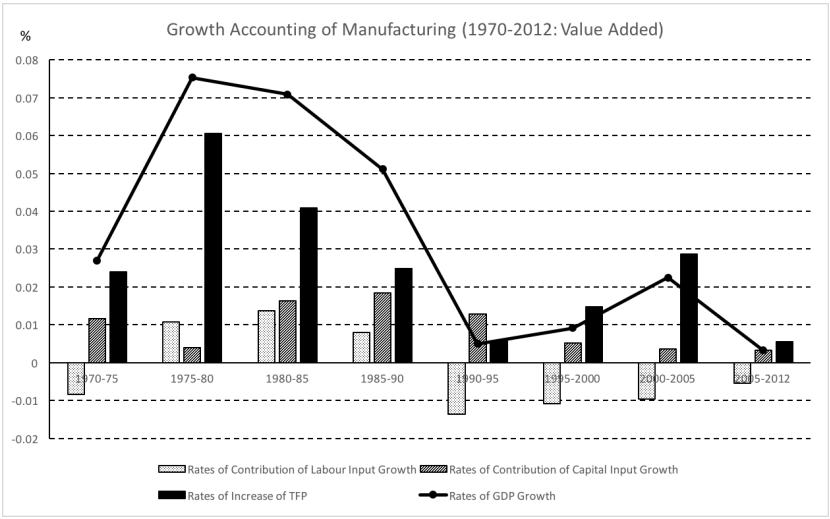
As representative examples, I previously show two quantitative indexes below. One is the growth accounting (see *Fig. 6*, *Fig. 7*, *Fig. 8*), and the other is the data of intangible assets (see *Fig. 9*, *Fig. 10*).



Source: JIP Database 2015 (Japan Industrial Productivity Database 2015)

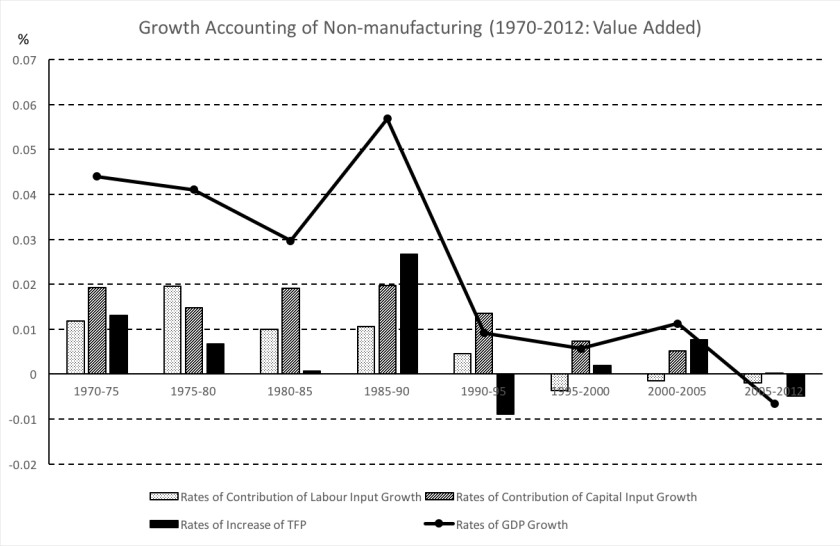
http://www.rieti.go.jp/jp/database/JIP2015/index.html

***Fig. 6*: Growth Accounting of Japan (1970-2012)**



Source: JIP Database 2015

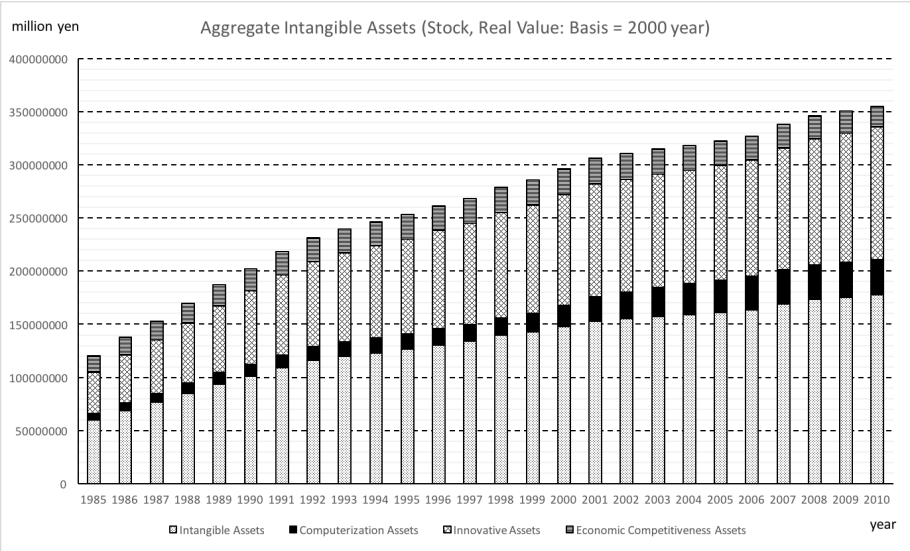
***Fig. 7*: Growth Accounting of Manufacturing Industry (1970-2012)**



Source: JIP Database 2015

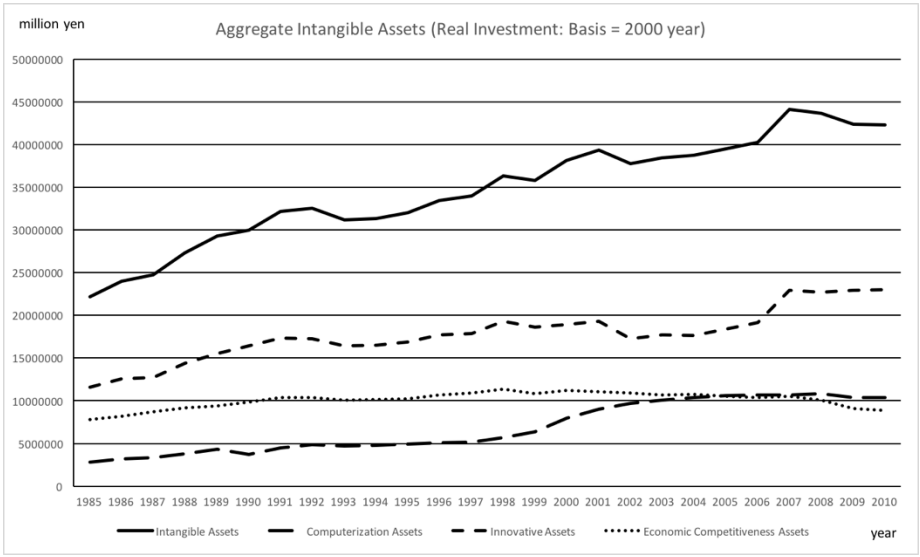
***Fig. 8*: Growth Accounting of Non-manufacturing Industry (1970-2012)**

According to ***Fig. 8***, the GDP growth rate has been fluctuating almost along with the rate of increase of TFP. Japan has been experiencing a low growth economy since 1990s, which is called "the lost twenty years" in Japan. In general, the concept of TFP contains human capital, technology, institutions, and so on. But whether TFP really shows real knowledge condition or not?



Source: JIP Database 2015

***Fig. 9*: The Real Value of Intangible Assets Stock (1985-2010)**



Source: JIP Database 2015

***Fig. 10*: The Real Investment to Intangible Assets (1985-2010)**

According to ***Fig. 9*** and ***Fig. 10***, a volume of intangible assets has been steadily increasing in Japan. But, the rate of contribution of TFP declined sharp sharply. Are these two facts inconsistent with each other?

4.2 New Growth Theory

In modern macroeconomic theory, especially, the so-called 'new growth theory', knowledge has been considered a critical factor for the recent economic growth. P. M. Romer has developed a neoclassical growth model by introducing a factor of knowledge explicitly. Using a handy summary by Jones (2008), the formation of Romer model is shown as ***Table 2***.

4 equations and 4 unknowns

Unknowns/endogenous variables:	Y_t, A_t, L_{yt}, L_{at}
Output production function:	$Y_t = A_t L_{yt}$
Idea production function:	$\Delta A_t = \bar{z} A_t L_{at}$
Resource constraint:	$L_{yt} + L_{at} = \bar{N}$
Allocation of labor:	$L_{at} = \bar{\ell} \bar{N}$
Parameters:	$\bar{z}, \bar{N}, \bar{\ell}, \overline{A_0}$

notations: Y_t: output, A_t: the stock of existing knowledge, L_{at}: the number of workers producing

ideas, L_{yt}: the number of workers producing output, $\bar{N}$: total population, $\bar{z}$: a productivity parameter, A_0: an existing stock of ideas at date $t = 0$, ΔA_t: the number of new ideas produced during period t, $\bar{\ell}$: the constant fraction of the population works in research

***Table 2*: A Structure of the Romer Model summarized by Jones (2008)**

A main characteristic of Romer model is in the distinction between objects and ideas. Then an idea production function is explicitly formulated. New ideas are produced in dependence on the existing knowledge stock and the number of workers producing ideas under the constraints of total population. It seems to be objective inputs that generate ideas. Therefore, I think the mechanism of emergence and fluctuation of knowledge stock is still indistinct. Anyway, it seems be significant that the role of knowledge is clearly recognized in the new growth theory. Schumpeterian growth model by P. Aghion and P. Howitt is located in the trend of the new growth theory.

The two main features of the 'original' Aghion and Howitt's Schumpeterian growth model are evident in its questioning of how labour investments should be distributed between independent R&D and production departments, and in its explicit formularization of R&D investment within the model. Additionally, there are two reasons why their theory might profess to be Schumpeterian. First, the occurrence of innovation is expressed using a Poisson process model of probability. This is similar to the Nelson-Winter model (Nelson and Winter 1982), which is possibly the most representative theoretical model of evolutionary economics today. Second, having established R&D divisions as separate from the production process, the model divides labour into that which is invested in the production process and that which is invested in R&D, and clearly specifies the significance of each. This reflects the historical changes in those responsible for innovation as capitalist economies have developed.

Nonetheless, while the former point incorporates the hit-and-miss character, or uncertainty, associated with innovation, ultimately, its objectives consolidate around an optimal R&D investment based on an expected payoff. Then, the latter point is reasonable if we consider the division of labour and the variance in knowledge levels. However, the model questions how labour, as a scarce resource, might be optimally distributed, while the knowledge levels for each labour type are left untouched, or are assumed as given. Thus, as a framework for the sort of dynamic analysis of knowledge-based economies I have been discussing, the model is not appropriate.

Now, in recent contributions by them and their followers[11], we would be able to grasp the implications which are different from past their Schumpeterian growth theory. In the matter of their recent changes in direction, I expect to prepare the next article.

4.3 The Econometric Analysis using a Knowledge Production Function

We find an explicit use of a knowledge production function in Pakes and Griliches (1984). They showed connections among factors in production activities with knowledge as *Fig. 6*. Although various actual factors were considered to construct a knowledge production function, after all, they assumed only 'past R&D expenditures produce productive knowledge.

Their econometric analysis of the contributions of knowledge to economic growth was applied the next knowledge production function.

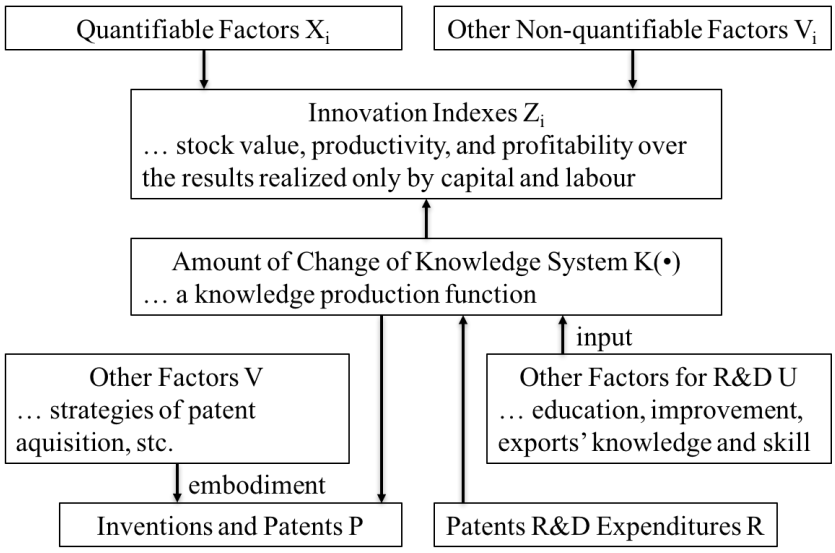
$$Y = A + \alpha K + \beta L + \gamma R$$

An Additional notation 'R' was assumed to be produced by past R&D expenditures. Moreover, 't' was the time lag from R&D expenditure to its contribution to production, which was estimated as the minimum = 1.17 years and maximum = 2.62 years. 'δ' was the rate of depreciation of knowledge, which was estimated as the average = 25% from the patent data. Then, the knowledge stock 'RS' which contributed every i year's production was expressed below.

$$RS = RS_{i-t-1}(1-\delta) + R_{i-t}$$

After all, the contribution of the knowledge stock to economic growth was analyzed by 'R' of previous equation was replaced to 'RS'.

[11] See Aghion, Akcigit and Howitt (2015).



Source: Pakes and Griliches (1984), p. 56

***Fig. 11*: Econometric Analysis Using a Knowledge Production Function**

I would be able to point out some weak points. First, only one factor 'R' is considered and others of 'U', 'V', and 'P' are not. Pakes and Griliches considered only factors which are grasped quantitatively and had no choice but to exclude qualitative ones like institutional and human factors. Second, the knowledge stock 'RS' is treated as the one which is independent of labour 'L'. Thus, they did not have the idea that the recombination of divisions of labour, that is, the recombination of the knowledge labour and the physical one through knowledge interactions. In other words, it seems unsuitable to understand a flesh-and-blood person with knowledge. Third, this econometric framework lacks non-market dimensions, especially institutional dimensions, furthermore institutional design by the government.

5. System Dynamics Modelling

5.1 A Preliminary consideration

In above mentions, I examined how to analyze modern knowledge capitalism with mainly two considerations. The bases of my approach should be required a process thinking of knowledge capitalism which maintains the logic of industrial capitalism and includes the interactions through knowledge. Here, the core subject would be how to relate non-market or institutional dimensions to knowledge reproduction processes.

Toward considering this subject, I examined capitalism itself and confirmed a need for redefining it compatible with its historical change. And I also examined the need for the division of knowledge in knowledge capitalism. On one hand, a relatively static side of knowledge is knowledge stock, on the other hand, a dynamic side is knowledge flow. The former is knowledge which gets into the inside of an organization and accumulates. It fluctuates continuously through above conversion. The latter needs the social and/or organizational context to convert it into the shape possible to accumulate.

An analytical framework of our awareness concerning NIS on knowledge seems to be similar to that of Kline and Rosenberg (1986). Their suggestion was the conversion from the linear model of innovation to the chain-like model of innovation[12]. Then I think that a more suitable method to analyze knowledge interacting system or knowledge network system is a tool of system dynamics (SD). It is said that SD developed in 1960s by Jay Wright Forrester who was a professor at the MIT Sloan School of Management. Recently, not only in business administration but also in evolutionary economics on innovation, research findings have been published (Janszen and Degenaars (1997), Sterman (2000), Lee and Tunzelmann (2005), Samara et al. (2012), and so on).

The characteristics of SD approach has some unique characteristics. Firstly, a formulation of a system is presented by causal loops. Secondly, causal loops represent feedback mechanisms. These mechanisms are both balancing negative feedback loops and reinforcing positive feedback loops. The former exhibits goal-seeking behavior so that after a disturbance, the system seeks to return to an equilibrium state. The latter suggests the presence of an unstable equilibrium because an initial disturbance leads to further change (Samara et al. 2012: 628). Thirdly, which is most important character, when we deal with a complex network system or observe dynamics and interactions between factors of stock and flow, we need not excessive mathematical skills and computer programing skills.

For the purpose of using an analytical tool of system dynamics, to begin with, I propose the 'knowledge version' Marxian-Schumpeterian diagram (see ***Fig. 12***) based on the Marxian-Schumpeterian diagram and the Schumpeterian hypothesis "Mark III." I think strong points of this framework can be mentioned as follows.

[12] This was also referred in OECD (1996).

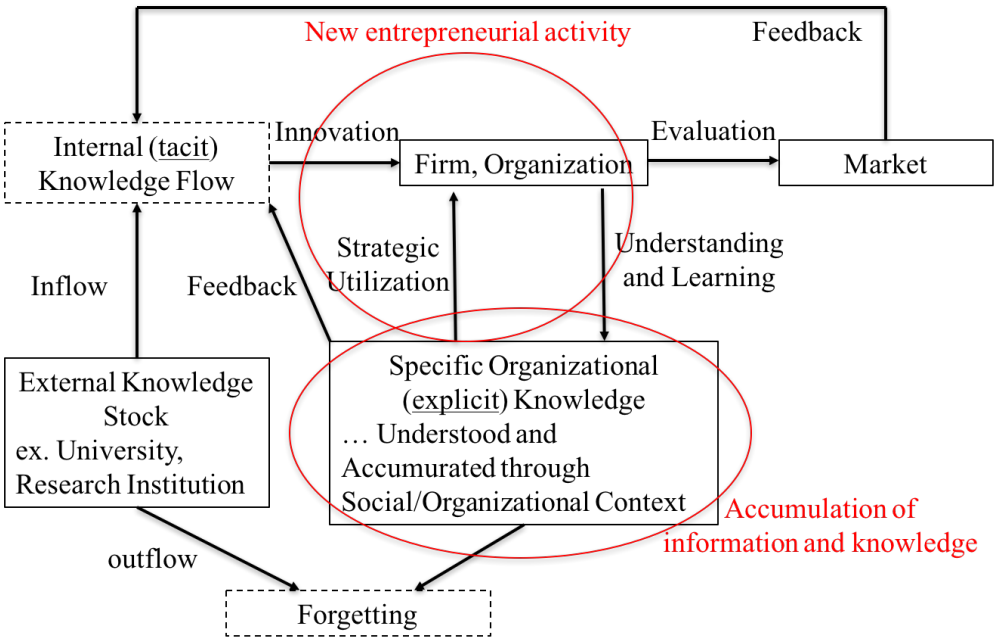


***Fig. 12*: A 'Knowledge version' Marxian-Schumpeterian Diagram**

1. We can consider interactions between the organizational context and each individual knowledge stock or between the internal knowledge stock and the external knowledge flow. That is to say, the organization and the individual understand and learn knowledge and use it strategically.
2. We can observe a process that organizations accumulate the organizational knowledge by converting external knowledge flow into internal explicit knowledge. In other words, knowledge is managed through institutions.

From the beginning, NIS is a macroeconomic concept so that I decided to construct my CD model as a macroeconomic system as same as Courvisanos (2012).

5.2 SD Modelling

I construct my SD model with STELLA. At the first step, I construct Marxian diagram of turnover of capital. This diagram contains three kinds of capital stock – 'Money Capital,' 'Productive Capital," and 'Commodity Capital' – and a volume of each capital stock fluctuates both inflow and outflow. And then they are correlated with each other by action connector arrows.

I take a step by step approach towards building NIS model in knowledge capitalism. Then, based on above Marxian diagram, I simply replace 'Productive Capital' to 'Knowledge Capital.' Of course, I understand that this operation is excessive simplification. However, if we recognize that productive

capital such as machinery, tools, and equipment crystalizes knowledge, it will be permitted that every productive capital seems to be considered knowledge capital. Then as a first step towards the definite introduction of knowledge with in a framework of NIS, I show a "Map" with STELLA (see ***Fig. 13***).

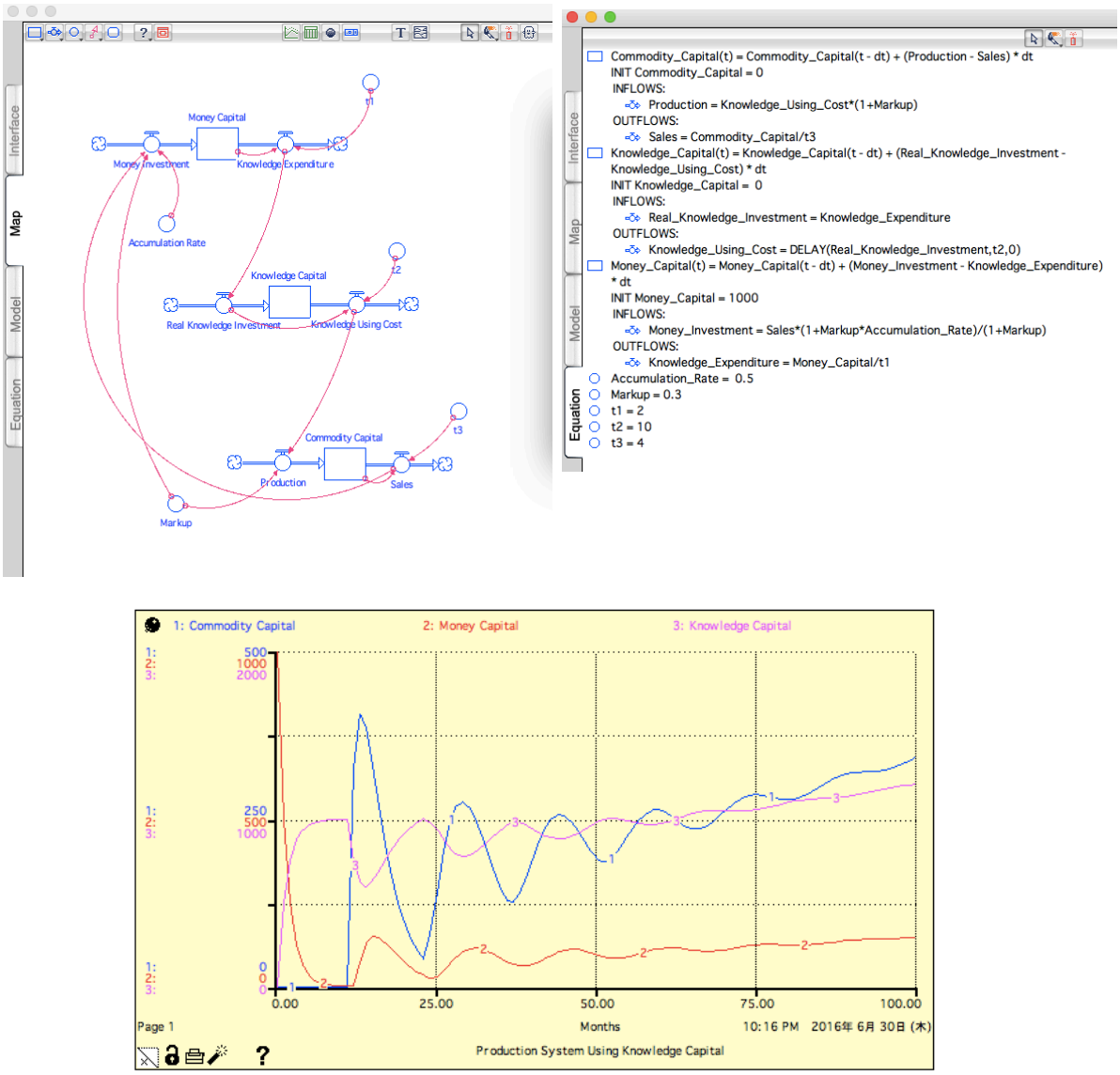
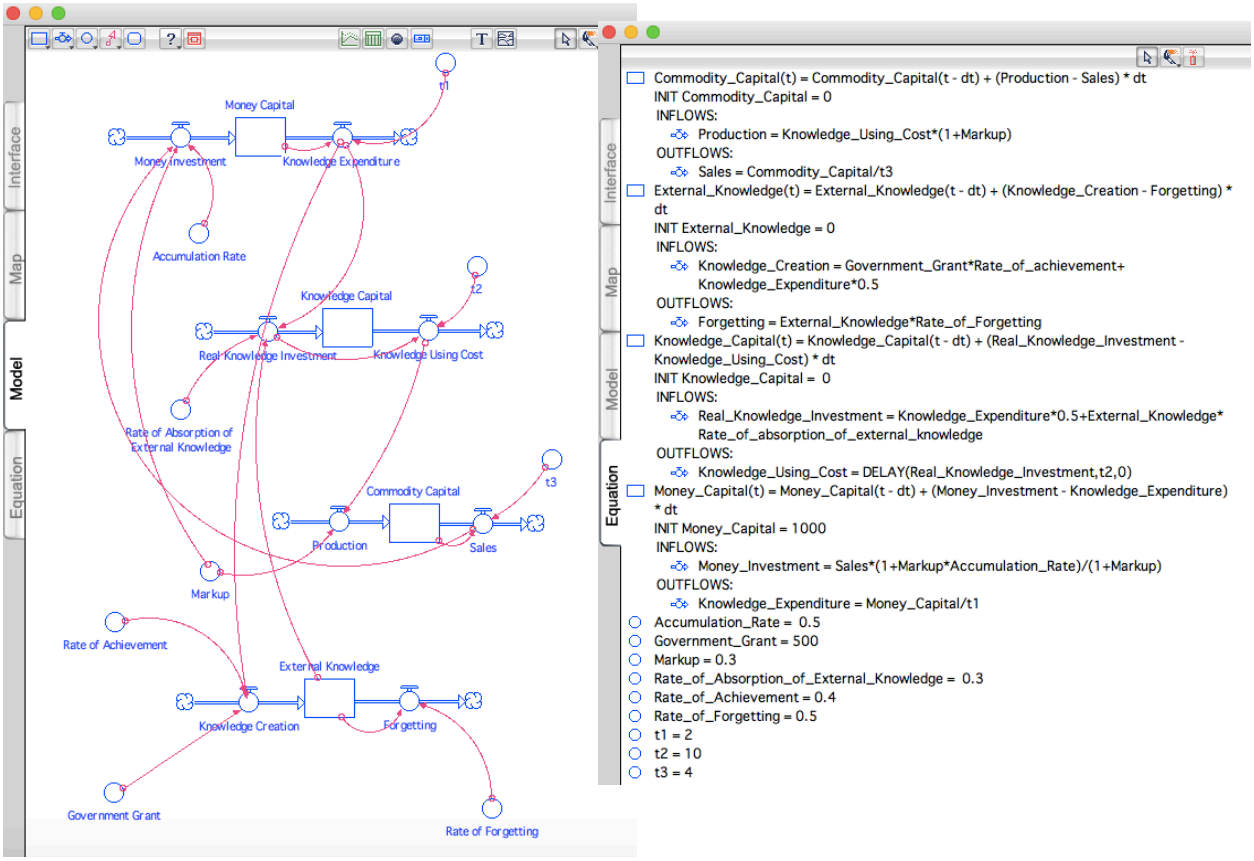


***Fig. 13*: Marxian scheme of Turnover of Capital within Knowledge Capital**

A lower graph in ***Fig.13*** shows a simulated result. For first 10 months, money capital is spended to construct knowledge capital to use it for commodity production. After this, the production model is running continuously and dividedly. At the thirteenth line shows in equations list, a DELAY function is used to convert "Real Knowledge Investment" flow into the flow of knowledge utilization after production period ("t2"). As a whole, three kinds of capital are increasing in stable state throughout

run times.

In the next step, I explicitly introduce “External Knowledge Capital” stock in a previous framework. I introduce here three additional conditions. The first is that the external knowledge stock is created by two inflows: “Government Grant” with “Rate of Achievement” and a part of “Knowledge Expenditure” from “Money Capital.” The second is external knowledge capital may be lost by the outflow of “Forgetting.” I think this outflow seems to be interpreted as depreciation of knowledge capital. The third condition is that “Knowledge Capital” is also reflected by additional two factors: “External Knowledge Capital” stock and “Rate of Absorption of External Knowledge.” Under the state that other conditions are unchanged, I practice this extended SD model (see ***Fig. 14***).



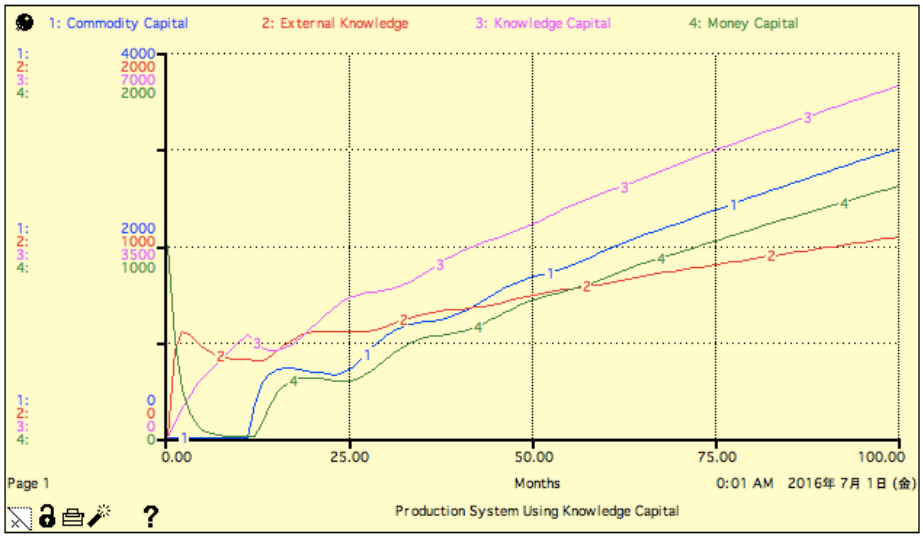


***Fig. 14*: Explicit Introduction of External Knowledge Capital**

The simulated result of the extended SD model shows that the growth of each capital is more enhanced. It seems to be an effect of added external knowledge capital stock.

In this section, I formulated one type of the macroeconomic NIS model based on Marx's systems perspective on capitalism. And then I constructed and practiced it as a SD model with STELLA. I must continue to extend and improve this SD model in the future research by using various functions of STELLA and empirical statistical data more effectively. In this pater, I particularly focused on SD modelling of NIS so that I could not enough to consider the institutional dimension which is needless to say one of the essential characteristics of NIS. But I think that institutional factors can be introduced by using STELLA in the same way as "External Knowledge Capital" in above extended model.

6. Conclusion

As a brief conclusion, I itemize some points of the examination in this paper.

- In this research, I examined how to analyze modern knowledge capitalism with mainly two considerations. The bases of my approach should be required a process thinking of knowledge capitalism which maintains the logic of industrial capitalism and includes the interactions through knowledge. Here, the core subject would be how to relate non-market or institutional dimensions to knowledge reproduction processes.
- I conclude that a more suitable method to analyze the knowledge interacting system or

knowledge network system is the system dynamics analysis. Finally, for the purpose of using the analytical tool of system dynamics, I propose the 'knowledge edition' Marx-Schumpeter diagram.

- Moreover, I put above now framework into practice with STELLA. I will bring out some implications from this system dynamics analysis, especially concerning how to design the allocation of efficient institutions in the national innovation system and how to change the economic outcomes according to the changes of the ways of interactions among heterogeneous agents with different knowledge.

References

Antonelli, C. ed. (2011). *Handbook on the Economic Complexity of Technological Change*. Edward Elgar.

Aghion, P., Akcigit, U. and P. Howitt (2015). "The Schumpeterian Growth Paradigm," *The Annual Review of Economics*, 7, 557-75.

Aghion, P. and P. Howitt (1992). "A Model of Growth through Creative Destruction," *Econometrica*, 60, pp. 323-51.

Bloch, H. and J. S. Metcalfe (2015). "Restless Knowledge, Capabilities and the Nature of the Mega-Firm," in Pyka, A. and J. Foster eds. (2015). *The Evolution of Economic and Innovation Systems*. Springer.

Burton-Jones, A. (1999). *Knowledge Capitalism*. Oxford University Press.

Courvisanos, J. (2012). *Cycles, Crises and Innovation*. Edward Elgar.

CRDS JST. (2007). *Chishiki wo Seisan, Katsuyousuru tameno Kagaku Kochiku heno Chosen* [The Challenge for Constructing Science toward Creation and Exploitation of Knowledge]. Center for Research and Development Strategy Japan Science and Technology Agency.

Dolfsma, W. and G. van der Velde (2014). "Industry Innovativeness, Firm Size, and Entrepreneurship: Schumpeter Mark III?," *Journal of Evolutionary Economics*, 24, pp. 713-736.

Dosi, G. (2013). "Innovation, Evolution, and Economics: Where We Are and Where We Should go," in Fagerberg, J., Martin, B. R. and E. S. Andersen eds. (2013). *Innovation Studies*. Oxford University Press.

Fagerberg, J. and K. Sapprasert (2011). "National Innovation Systems: The Emergence of a New Approach," *Science and Public Policy*, 38(9), pp. 669-679.

Freeman, C. (1987). *Technology Policy and Economic Performance: Lessons from Japan*. Pinter Publisher.

Freeman, C., Clark, J. and L. Soete (1982). *Unemployment and Technical Innovation*. Greenwood Press.

Freeman, C. and F. Louçã (2001). *As Time Goes by*. Oxford University Press.

Foray, D. and B.-Å. Lundvall (1998). "The knowledge-Based Economy," in Neef, D., Siesfeld, G. A. and J. Cefola eds. *The Economic Impact of Knowledge*. Butterworth-Heinemano.

Godin, B. (2009). "National Innovation System: The System Approach in Historical Perspective," *Science, Technology and Human Values*, 34(4), pp. 476-501.

Handa, M. (2007). "'Johoka' wo Shijiku ni Gendai Shihonshugi wo Miru [Information Capitalism, A Theoretical Perspective for Contemporary Capitalism]," JSPE ed., *Kikan Keizai Riron* [Political Economy Quarterly], 44(2), pp. 5-17 (in Japanese).

Imai, K. (1989). "Joho, Gijutu to Keizaiseido [Information, Technology, and Economic Institutions]," Imai, K. ed., Kawamura, N. trans., *Purosesu to Nettowa-ku* [Processes and Networks]. NTT Shuppan, Chap. 5 (in Japanese).

Janszen, F. H. A. and G. H. Degenaars (1997). "A Dynamic Analysis of the Relations between the Structure and the Process of National Systems of Innovation Using Computer Simulation," *Research Policy*, 27, pp. 37-54.

Jones, C. I. (2008). *Macroeconomics*. W. W. Norton & Company.

Kitamura, H. (2003). *Joho Shihonshugiron* [A Theory of Information Capitalism]. Otsuki Shoten (in Japanese).

Kline, S. J. and N. Rosenberg (1986). "An Overview of Innovation," in Landau, R. and N. Rosenberg eds., *The Positive Sum Strategy*. National Academy Press.

Kurz, H. D. (2012). *Innovation, Knowledge and Growth*. Routledge.

Langlois, R. (2007). *The Dynamics of Industrial Capitalism: Schumpeter, Chandler, and the New Economy*. Routledge.

Lee, T. L. and N. Tunzelmann (2005). "A Dynamic Analytic Approach to National Innovation Systems, *Research Policy*, 34, pp. 425-40.

Loasby, B. J. (1999). *Knowledge, Institutions and Evolution in Economics*. Routledge.

Lundvall, B.-Å. ed. (2010). *National Systems of Innovation*. Anthem Press.

Mathews, J. A. (2002). "A Resource-based View of Schumpeterian Economic Dynamics," *Journal of Evolutionary Economics*, 12, pp. 29-54.

Marx, K. (1906). *Capital*, Vol. 1., Kerr.

Metcalfe, J. S. (2001). "Institutions and Progress," *Industrial and Corporate Change*, 10, pp. 561-86.

Metcalfe, J. S. (2002). "Knowledge of Growth and the Growth of Knowledge," *Journal of Evolutionary Economics*, 12, pp. 3-15.

Metcalfe, J. S. (2009). "Restless Capitalism," in Amatori, F. and M. Amendola eds., *Ricerca avanzata e alta divulgazione: Le Momigliano Lectures 1997-2008*. ICSIM.

Metcalfe, J. S. and J. Foster (2010). "Evolutionary Growth Theory," in Setterfield, M. ed., *Handbook of Alternative Theories of Economic Growth*. Edward Elgar.

Metcalfe, J. S. and R. Ramlogan (2005). "Limits of the Economy of Knowledge and Knowledge of the Economy," *Futures*, 37, pp. 655-674.

Nakaoka, T. (1970). *Kojo no Tetsugaku* [Philosophy of the Factory]. Heibon sha (in Japanese).

Nelson, R. R. ed. (1993). *National Innovation Systems*. Oxford University Press.

Nelson, R. R. and S. G. Winter (1982). *An Evolutionary Theory of Economic Change*. Harvard University Press.

Nishibe, M. (2011). *Shihonshugi ha Doko he Mukaunoka* [Where Capitalism Goes to?]. NHK Books (in Japanese).

Nonaka, I. (1998). "The Knowledge-Creating Company," in Neef, D., Siesfeld, G. A. and J. Cefola eds. *The Economic Impact of Knowledge*. Butterworth-Heinemano.

Nonaka, I. and H. Takeuchi (1995). *The Knowledge-Creating Company*. Oxford University Press.

Nonaka, I., Toyama, R. and T. Hirata. (2008). *Managing Flow: A Process Theory of the Knowledge-Based Firm*. Palgrave Macmillan.

OECD. (1996). *The Knowledge-based Economy*. OECD.

OECD. (1997). *National Innovation Systems*. OECD.

Okishio, N. (1993). *Keizaigaku ha Ima Nani wo Kangaeteiruka* [Now, What Economics Think?]. Otsuki Shoten (in Japanese).

Pakes, A. and Z. Griliches (1987). "Patents and R&D at the Firm Level," in Griliches, Z. ed., *R&D Patents, and Productivity*. University of Chicago Press, pp. 55-72.

Penrose, E. (2009). *The Theory of the Growth of the Firm*, 4th edition. Oxford University Press.

Perez, C. (2002). *Technological Revolutions and Financial Capital*. Edward Elgar.

Piketty, T. (2014). *Capital in the Twenty-First Century*. Belknap Press.

Ramlogan, R. and J. S. Metcalfe (2006). "Restless Capitalism," in Garnsey, E. and J. McGlade eds., *Complexity and Co-Evolution*. Edward Elgar, pp. 115-146.

Rosenberg, N. (1974). "Karl Marx on the Economic Role of Science," *Journal of Political Economy*, 82(4), pp. 713-28.

Samara, E., Georgiadis, P. and I. Bakouros (2012). "The Impact of Innovation Policies on the Performance of National Innovation Systems: A System Dynamics Analysis," *Technovation*, 32, pp. 624-38.

Schumpeter, J. A. (2002). "The Economy as a Whole: Seventh Chapter of the Theory of Economic Development," translated by U. Backhaus, *Industry and Innovation*, 9(1/2), pp. 93-145.

Silverberg, G. and B.Verspagen (1994). "Learning, Innovation and Economic Growth," *Industrial and Corporate Change*, 3, pp. 199-223.

Soete, L., Verspagen, B. and B. ter Weel (2009). "Systems of Innovation," Working Paper Series (UNU-MERIT), #2009-062.

Smith A. (2007). *An Inquiry into The Nature and Causes of the Wealth of Nations*, Soares, S. M. ed. MetaLibri Digital Library.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modelling for a Complex World*. McGraw-Hill.

Takeuchi, H. (2013). "Knowledge-Based View of Strategy," *Universia Business Review*, Quarto Trimestre 2013, pp. 68-79.

Teece, D. J. (2010). "Technological Innovation and the Theory of the Firm," in Hall, B. H. and N. Rosenberg eds., *Handbook of the Economics of Innovation*, Vol. 1. North-Holland.

Witt, U. (2002). "How Evolutionary is Schumpeter's Theory of Economic Development?," *Industry and Innovation*, 9(1-2), pp. 7-22.