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Effectiveness of corporate R&D: An analysis of Japanese experience in 1990's

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Abstract

Japanese R&D seems less efficient in 1990's than in 1980's. The emergence of radical innovations in 1990's and the increased need of division of labor in R&D were examined as possible factors that explain the deterioration. Japanese R&D was performed primarily by large firms that had strong inclination to secure a complete set of key technologies in-house rather than to specialize in specific technologies. Those large corporations might be less efficient in early phase of radical innovation, where a number of trials and errors are necessary. The weakness of Japanese service sector resulted in relative inefficiency of Japanese ICT in development phase and its less effectiveness in application stage. Limited internationalization of Japanese R&D is a serious problem when international division of labor becomes a necessary condition for successful R&D.

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1. Introduction

In the fiscal year 2002, Japan spent 16.7 trillion yen in research and development, which corresponds to 3.15% of its GDP. This makes Japan one of the most R&D intensive countries in the world. The Japanese ratio surpassed that of the United States in mid 1980's and has been higher ever since. However, Japanese economy experienced difficulties in 1990's, while the U.S. economy enjoyed a substantial growth. U.S. average annual growth rate between 1991 and 2003 is almost 3% and is more than double of Japanese growth rate. Not only the growth rate, but multi-factor productivity figures are also more favorable to the United States. Between 1990 and 2001, U.S. productivity increased at an average annual rate of 1.01%, while the corresponding figure for Japan was 0.70%.

It is a common understanding that technology is an important factor of economic growth and that technological innovation leads to higher productivity. If Japan has been allocating, in relative terms, more resources to R&D, it would normally have a higher productivity growth. Above mentioned result is contrary to this assumption and suggests that research and development activities in Japan are, for some reasons, less efficient or less effective than in the United States. [1]

The 2001-2002 version of "Annual Report on the Japanese Economy and Public Finance" pointed out this discrepancy and indicated two "problems with Japan's R&D". First, the report said that the quality of Japanese R&D was inferior, as evidenced by low citation index of Japanese papers and by technology trade deficit in high-tech areas. Second, the report cited the argument of "some people" that "many R&D achievements (in Japan) have remained within universities and companies' research laboratories and have failed to be effectively utilized". [2]

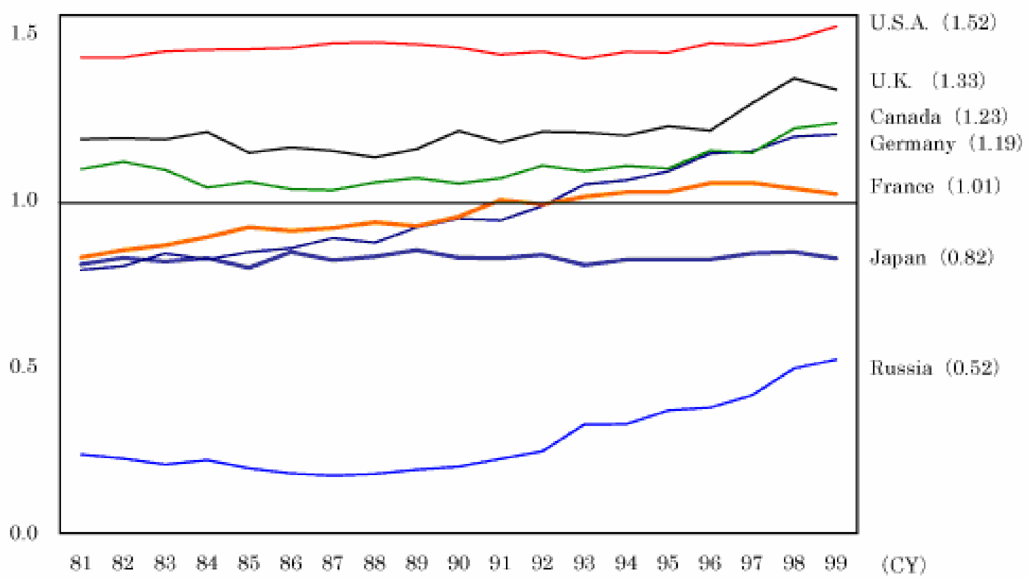
These are interesting arguments, but they do not address one question of critical importance: why these problems are more serious in 1990's than in 1980's. Possible explanations for this change can be grouped into two; those related to Japanese R&D

[1] Total factor productivity or multi-factor productivity is a function of a number of factors other than technology. The relation between technology and productivity needs a separate discussion. In this paper it is simply supposed that technology is a major factor of productivity growth.
[2] Cabinet Office (2002) Chapter 3, Section 2, 4.

system itself and those related to factors of more global nature. The first group of explanations ("endogenous explanations") would maintain that the quality of Japanese R&D is lower in 1990's than in 1980's, or that the utilization of R&D achievements became less effective in the later decade. The second group of explanations ("exogenous explanations") would focus on some changes that took place outside of Japanese R&D system itself and affected its effectiveness.

The endogenous explanations do not seem to be supported by evidence. For example, the quality of Japanese R&D as measured by citation index remained at about the same level. The relative citation index (RCI) referred to in the Cabinet Office annual report remained around 0.8 and did not show any significant deterioration between 1981 and 1999.

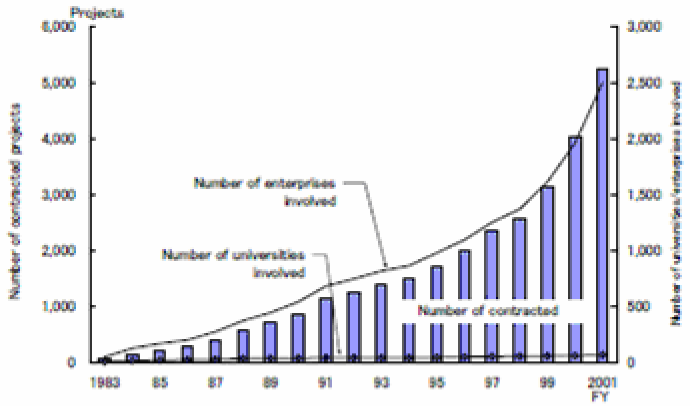
Figure 1: Changes in Relative Science Citation Indexes of Major Countries



Source: Cabinet Office (2002) Figure 3-2-21

Nor is it probable that the R&D achievements by universities were less used by Japanese industry in 1990's than in 1980's. On the contrary, the relation between Japanese universities and industries became closer during the period, as indicated by a significant increase in number of joint research projects between national universities and business enterprises.

Figure 2: Trends in the number of joint research projects
between national universities and business enterprises



Source: NISTEP (2004) p.208

It is then likely that the deterioration of effectiveness of Japanese R&D in 1990's was caused primarily by exogenous factors. This paper suggests two of such factors; 1) the emergence of radical innovations and 2) the increased need of division of labor in R&D. As Japanese R&D system is more adapted to incremental innovation than to radical innovation and as its main R&D activities are performed by large corporations that are inclined to keep as much key technologies in-house as possible, these changes affect its effectiveness. Before discussing these two changes and their impact on Japanese R&D system, we will make a preliminary examination of the notion of technology and innovation in section 2. In sections 3 and 4, we describe each of the two changes and their impact on Japanese R&D system. We will conclude the paper by summarizing the sections 3 and 4 and by suggesting subjects for further studies.

2. Preliminary examination of the notion of technology and innovation

Technology is the practical application of knowledge especially in a particular area. In a modern economy, technology has been developed into systematized body of specialized knowledge. Technological knowledge is taught at school and traded in the form of patent and other types of intellectual property. However, the essence of technology is its applicability to specific problem solving. The actual application of technology supposes adaptation to the problem and it varies with the economic agent and its environment.

This aspect of technology has been reiterated by institutional theory of technological innovation. Daniele Archibugi and Jonathan Michie summarized the central conclusion of this school of theory in following four points.

1) Technology is often proprietary in nature (as opposed to a public good). Would-be imitators can acquire technological competence but this is a costly, time-consuming process so that there will inevitably be some uncertainty about whether the economic returns obtained will repay the costs of imitating the innovation.
2) Only a part of knowledge is codifiable in handbooks, blueprints, patents, scientific articles, etc. There is an equally important part of knowledge which is tacit and which can only be acquired by long process of learning. Knowledge is specific to economic agents such as individuals, firms, industries and nations.
3) There are fundamental variations across different technological fields. Each technology system, industry and country has a specific regime of technological appropriation which makes the innovations either more freely available or else more proprietary in nature.
4) The evolution of knowledge is highly path-dependent, that is, it is influenced by the knowledge already accumulated by economic agents in the past.[3]

In order to be effective and achieve innovation, technology has to be embodied into equipment, enacted by a new organization, or materialized in some other forms. In other words, technology is a means for an economic agent to create a more effective structural coupling with its environment, which means, for a firm, realizing higher sales and profits. The structural coupling is achieved through continuous interactions between the agent and its environment. The environment of an economic agent is composed of a number of elements. Some of them are economic agents themselves, such as workers, suppliers of materials and equipments, financial institutions, distributors and consumers. Based on this notion of technology and innovation, it is possible to classify innovation into different categories.

It is common to distinguish product innovation and process innovation. Product innovation is an innovation where a new or improved product is introduced. Process

[3] Archibugi and Jonathan ed. (1998) p.4

innovation is where an existing product is made in a new and less expensive way. These two types of innovation are often linked. However, the environment for product innovation and that for process innovation are quite different. In focusing on agents involved, one can summarize the difference as follows.

Table 1: Comparison of product innovation and process innovation

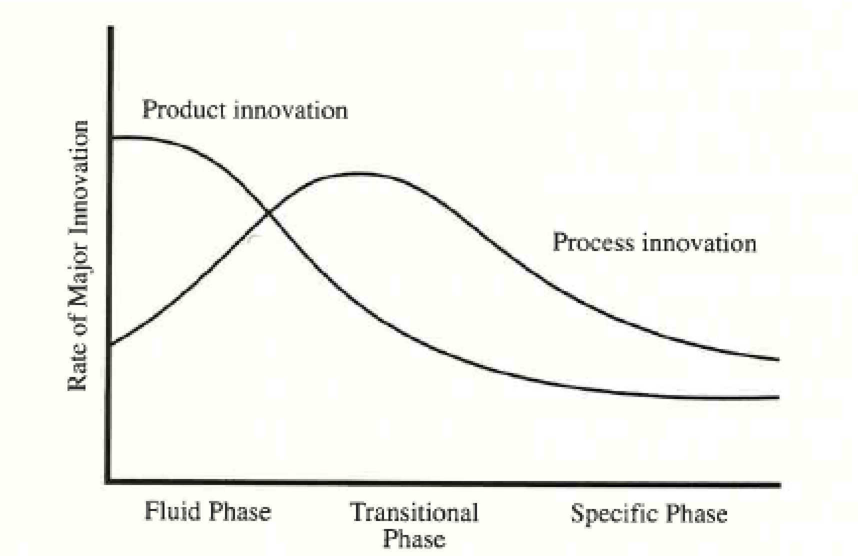
	Product innovation	Process innovation
Internal agents	Planning division Sales division	Production division
External agents	Customer Distributor	Material supplier Equipment supplier

In product innovation, interaction with customers is essential. In process innovation, most important external agents are material suppliers and equipment suppliers. If a firm has a pool of forward-looking customers with high competence, it is in a good position to create an innovative product. Close relations with competitive suppliers facilitate process innovation.

James Utterback proposed a model of industrial innovation with three phases.[4] The first phase ("fluid phase") proceeds in the face of both target and technical uncertainties and is characterized by frequent major product changes. In the second phase ("transitional phase"), a product innovation is accepted by the market and a dominant design emerges. The focus of firms begins to shift to process innovation. The third phase is named "specific phase" because the manufacturing of assembled products aims at producing a very specific product at a high level of efficiency. The linkages between product and process become very close in this phase.

Figure 3: The Dynamics of Innovation

[4] Utterback, James (1994) chapter 4



Source: Utterback (1994) p.91

Figure 3 shows the three phases of innovation with changing level of product and process innovations.

3. Radical innovations in 1990's and Japanese R&D system

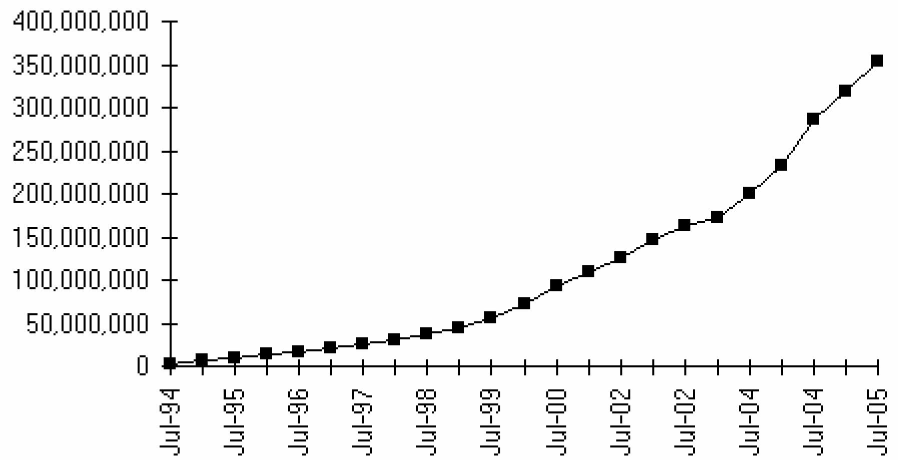
In this section, we will take internet as an example of radical innovation and discuss two characteristics of R&D in this area: 1) major role of small firms and 2) intensive use in service sector. Before discussing these characteristics and their impact on Japanese R&D system, we will review briefly the development of internet.

3-1 Rapid growth of internet

In 1990's emerged a number of innovations in various areas, including information and communication technology, life science and nano-technology. Internet is certainly one of the most radical among them, in the sense that it has spread all over the world in several years and that it has had the biggest impact on economic activities.

Technological basis of Internet was created by ARPAnet program started by the U.S. Department of Defense in 1969. However, its rapid expansion was brought about by the introduction of World-Wide-Web service in early 1990's. The idea of the service came from Tim Berners-Lee, who was a researcher at European Organization for Nuclear Research known as CERN. Mark Andreessen and his friends, who were working at the National Center for Supercomputing Applications (NCSA) at the University of Illinois, created a Web browser with graphic interface, which facilitated and rapidly expanded the use of this service.

Figure 4: Internet Domain Survey Host Count



Source: Internet Software Consortium (www.isc.org)

As shown in Figure 4, the number of Internet Domain Host has grown from almost nothing to more than 350 million in ten years. There are 875 million internet users in the world.[5] Internet continues to multiply its economic impact and it is too early to define its extent, but it has already changed considerably the way we communicate and the way we purchase. In Japan, electronic commerce in the area of business to business transactions amounted to 102 trillion yen in 2004, which represented 14.7% of all transactions.

3-2 Major role of small firms

The case of internet fits the innovation model of Utterback very well. Utterback mentions that, as the innovation develops itself in three phases, the organization that plays a central role changes "from entrepreneurial *organic* firm to hierarchical *mechanistic* firm

[5] UNCTAD (2005) p.2

with defined tasks and procedures”. [6] It is a well known fact that small firms, particularly start-up companies, have played an important role in the development of internet. Table 2 lists some of the best known companies in this area.

Table 2: Companies grown with internet

Name	Founded in	Annual sales	Products/Services
Cisco Systems	1984	$24.8 billion	Networking hardware/software
Yahoo!	1994	$5.26 billion	Online products and services
Amazon.com	1995	$8.49 billion	Online retail
eBay	1995	$4.55 billion	Online commerce
Google	1998	$4.22 billion *	Search engine

* nine months ended September 2005

All of the five firms listed above were supported by venture capital at initial stage. Three of them are founded by university researchers or by students. It is not a coincidence that small firms play an important role in the fluid phase of innovation. As a new technology like internet is introduced in the market, numerous trials and errors are made before some winning products and services are identified. Small firms are good at quick decisions and better adapted to high-risk, high-return situation, particularly when they are supported by venture capital funding.

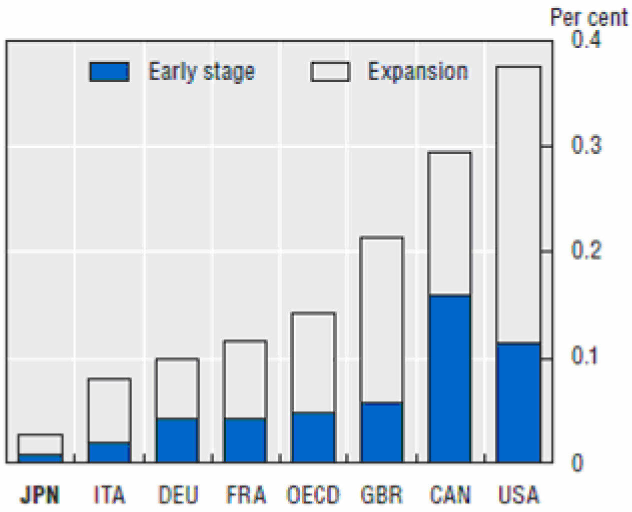
Larger firms can take advantage of R&D results of these firms by getting a license for the use of technology or by acquiring the company. Cisco Systems adopted an explicit policy of acquiring start-up companies that have technology complimentary to its portfolio. It acquired more than 100 companies between 1993 and 2005. By the series of acquisitions, Cisco Systems was able to build up technological capability to offer a wide variety of internet connecting hardware and software.

This is precisely the point where Japanese R&D system is weak. Japanese R&D activities are heavily concentrated in large corporations and small firms are not as active as

[6] Utterback (1994) p.91

in other developed economies. Figure 5 shows the venture capital investment flows of major countries. Japanese venture capital flow is by far the lowest among them.

Figure 5: Venture capital investment flows as a percentage of GDP, average 2000-03



Source: OECD (2006) p.97

There are several reasons for this relative weakness of small firms in Japan. First, Japanese financial institutions were not good at managing risks. Because protected by strict regulations for a long time, Japanese financial institutions avoided taking risks. They were not active in the development of new financial products or in investment in high risk areas. As a result, their expertise in these areas remains quite limited.

Second, mobility in Japanese labor market was low. Job-hopping was often considered to be a sign of failure. Bright young people preferred large corporations because they offered high social status, job safety, and relatively high income. Payment system as well as the importance of personal relations within a company encouraged employees to stay long. As job offer for mid-carrier people was limited, it was quite risky to quit a company to start his or her own. It was also difficult for a new company to hire talented people with work experience.

Third, Japanese companies have a very conservative procurement policy. As they are more interested in long term relations and as they are not willing to take risks, they often prefer suppliers with established reputation, even if their products are more expensive or lack features offered by small firm's products.

It is difficult to determine whether these factors are historical and likely to change in the near future, or they are cultural and likely to stay for a while. It is a historical fact that, after the second world war, there came a number of new companies that later became industry leaders, such as SONY and Honda. But it seems also true that Japan remains a "vertical society" as defined by Chie Nakane more than thirty years ago.[7]

Being a vertical society is not necessarily bad in itself. One has only to remember that in 1980's Japanese system was said to be a model for other economies. But it is certainly the case that low mobility in labor market and risk-avoiding tendency do not constitute a favorable environment for start-up companies. When there is a radical innovation like internet and when start-up companies are major players, the weak points of Japanese system are magnified.

3-3 Intensive use in service sector

Internet is used by a wide variety of industries, but service sectors including finance, transportation, and wholesale and retail trade are the areas where internet technology is intensively applied. Amazon.com is an example of a new service sector company created by internet technology. But existing large corporations have also taken advantage of this new technology. Wells Fargo, FedEx and Wal-Mart are the examples of successful early adopters.

As mentioned in Section 2, product innovation is realized through interactions between suppliers and customers. It is particularly important in the fluid phase where new products and services are not clearly defined yet. In this early phase, requirements from customers guide development process. Competent customers are quite valuable resources for product developers.

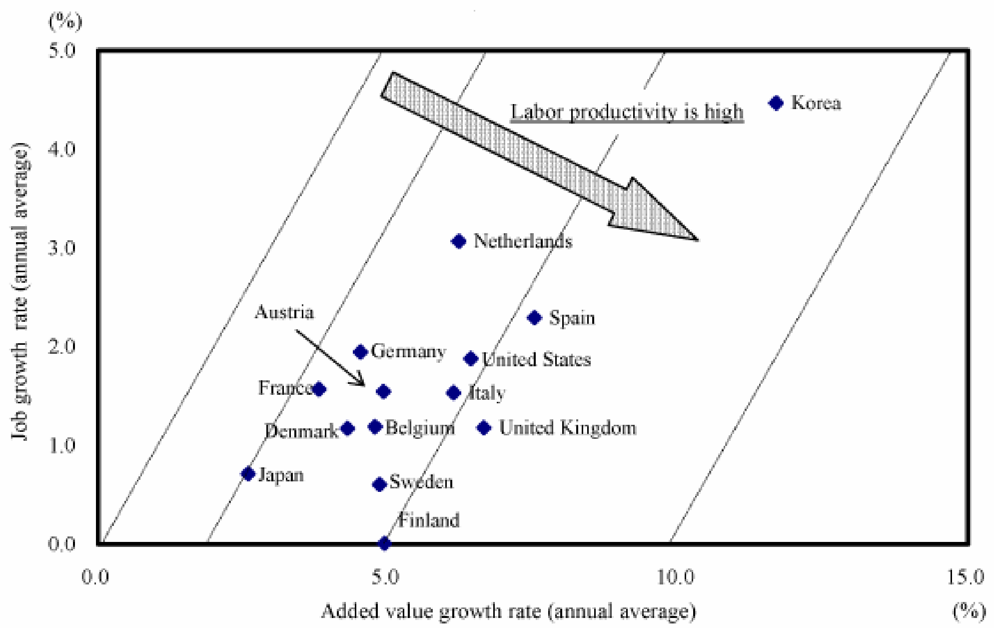
The problem for Japanese developers of internet technology is that Japanese service sector is weak. International competitiveness of Japanese banks, wholesalers, transportation companies are not high. In addition, many of these companies are not knowledgeable about information and communication technologies (ICT). Chief Information

[7] Nakane (1970)

Officer in these companies is usually passive, if not nonexistent.

Japanese service sector's productivity is growing but much more slowly than in other developed economies as shown in Figure 6. It is likely that one of the reasons of this low productivity growth is inefficient use of ICT in Japanese service sector.

Figure 6: The added value growth rate and job growth rate of the market service industry (1990-2002)



Notes: 1. *OECD STAN Indicator database*, OECD.
2. Figures for Japan, the United States, and Korea are for the period 1990 to 2001; figures for Germany are for the period 1991 to 2001.

Source: Cabinet Office (2006), Figure 3-4-9

In other words, the relative weakness of Japanese service sector and the increased importance of this sector in the internet age as a major user of the new technology have lead to low performance of Japanese economy and relative ineffectiveness of its R&D activities.

4. The increased need of division of labor in R&D

The second exogenous factor that affected Japanese R&D system is the increased need of division of labor in R&D. Michael Gibbons and others suggested that a new mode or knowledge production was emerging and named this “Mode 2”. They identified attributes of knowledge production in Mode 2 as follows. [8]

1) Knowledge Produced in the Context of Application

Knowledge is intended to be useful to someone and is always produced under an aspect of continuous negotiation.

2) Trans-disciplinarity

It assembles a diverse range of specialists to work in team and it develops a distinct but evolving framework to guide problem solving efforts.

3) Social Accountability and Reflectivity

Social accountability permeates the whole knowledge production process. The individuals themselves cannot function effectively without reflecting all the actors involved.

4) Quality Control

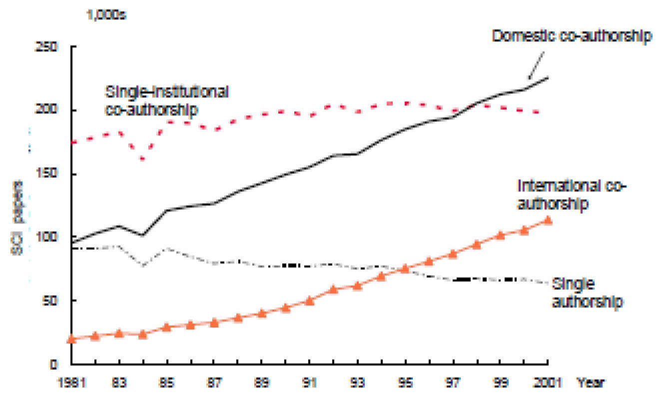
To the criteria of intellectual interest, other criteria are added through the context of application, which incorporates a diverse range of social, economic or political interests.

According to the authors, Mode 2 does not replace traditional mode of knowledge production (Mode 1), but it is complementary to it. It is particularly active in new areas. The reasons why Mode 2 emerged are a) the increased number of competent research sites as a result of mass education, b) the development of rapid transportation, as well as information and communication technologies, which permit extended cooperation and c) the expansion of the requirement of specialist knowledge on the demand side, stimulated by increased competition.

One could agree or disagree with the definition or use of the word “Mode 2”, but it seems undeniable that there is a clear tendency toward increased collaboration among researchers and among research organizations, with a view to solving questions efficiently in a more and more competitive environment. In other word, division of labor is developing in R&D activities.

[8] Gibbons, *et al* (1994) pp.3-8

Figure 7: Change in authorship of papers (Trends in the number of SCI papers by authorship)



Source: Compiled by NISTEP based on Thomson ISI's "Science Citation Index, Compact Disk Edition"

Source: NISTEP (2004) p. 162

Figure 7 shows that domestic co-authored papers and international co-authored papers are increasing significantly, while papers authored by a single institution or by a single author are stagnant.

This change will pose serious problems with Japanese firms for several reasons. First, Japanese firms are strongly inclined to in-house R&D. Second, Japanese firms' R&D activities are less internationalized. Third, because of limited experience in cooperation in R&D or trade in technologies, supporting services for R&D are insufficient in Japan. We will examine these factors in the following sub-sections.

4-1 Japanese firms' strong inclination toward in-house R&D

Japanese firms prefer to have a complete set of key technologies by themselves rather than to specialize in some specific technology. This tendency can be seen, for example, by the fact that Japanese major electronic firms have a very similar product portfolio.

To try to have a complete set of key technologies can be a good strategy. If a firm has a complete set of technologies needed to create a product and if the firm is advanced in all of these technologies, it will certainly be in a very strong position. That was the case with IBM in 1960's. Having a full range of technologies can also be an advantage for developing integrated system products.

However, it is becoming extremely difficult, if not impossible, for a firm to be competitive in a wide variety of technologies, because of the advancement and the specialization of technology, on the one hand, and because of the increased competition among growing number of firms with high competence, on the other.

Patent pool is an example which shows the necessity of cooperation in today's R&D activities. A patent pool is an agreement among patent owners to license a set of their patents to one another or to third parties. A patent pool is a useful mechanism, when a large number of patents held by different entities are necessary to create a product. It would be too cumbersome to establish a network of bilateral licensing agreements among all the firms concerned. MPEG-2 is a well-known example of patent pool and MPEG LA is the largest of MPEG-2 related pools. It involves more than 700 patents owned by 24 entities.

Japanese firms are aware of the necessity of cooperation and several of them are members of MPEG LA. However, as their strategy has long been narrowly focused on strengthening their own technological portfolio, they are having difficulty in adapting to the era of strategic alliance.

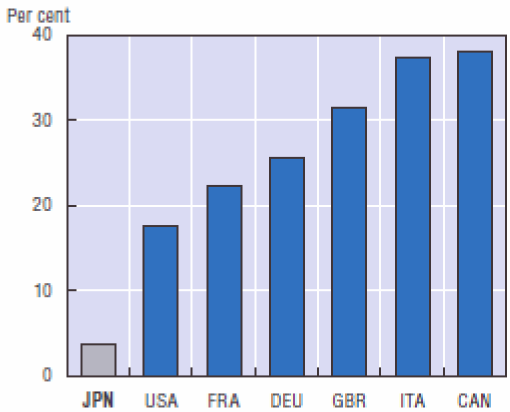
We should note that cooperative R&D activities do exist in Japan. As a matter of fact, these activities are the basis of their competitive process technologies. However, majority of these activities are cooperation between a large firm and its smaller suppliers. This kind of cooperation is often characterized by its informal nature. Sometimes, there is no written contract, and even if there is one, its clauses are not always respected. The informal nature is not necessarily bad and there are cases in which these symbiotic relations are developed into a very close tie among companies and contributed to competitiveness. But, they are limited in scope by its nature and not applicable to cooperation with firms that have a different cultural or legal background.

We should also mention the existence of government-led cooperative programs in Japan. VLSI project in late 1970's is the best known example. But the success of VLSI project may be an exception rather than a rule. Many of the government-led cooperative programs were in reality an assemblage of independent projects performed by participating firms and not a fully integrated R&D activity. And the fact that Japanese firms needed government leadership may be an indication of the difficulty they experienced in establishing cooperation among them.

4-2 Less internationalized R&D activities of Japan

R&D activities in Japan are less internationalized than most developed economies. Figure 8 shows R&D expenditure under foreign control in total manufacturing R&D of major developed economies. The share in Japan is by far the lowest.

Figure 8: Share of R&D expenditure under foreign control in total manufacturing R&D, 2002



1. 1998-2001 for Japan.

Source: OECD (2006), p97

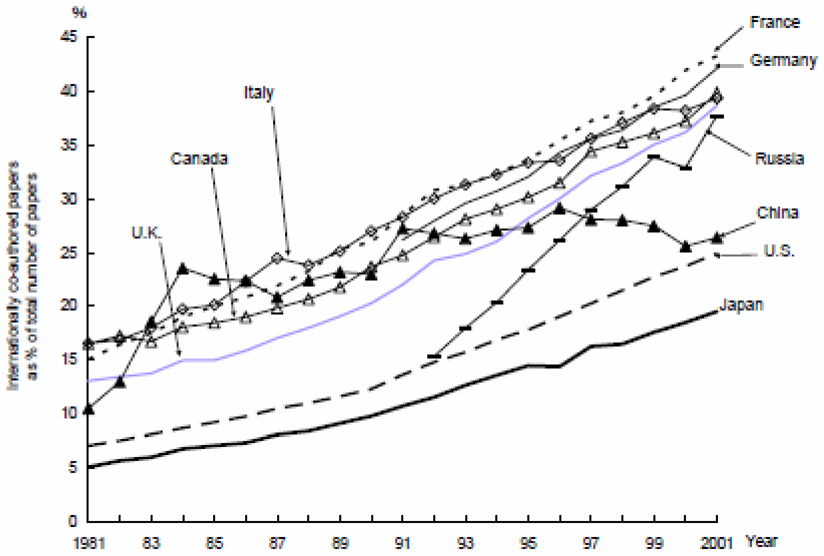
This low share can be explained by geographical and historical factors. Different from European countries, Japan had no developed economies nearby and could not develop horizontal division of labor with neighboring partners. It has much less immigrants than Europe or the United States. We should also point out that foreign investment in Japan was restricted until 1960's and that lower mobility in Japanese labor market was a barrier for foreign direct investment.

It is a fact that some Japanese corporations are performing active R&D in the U.S. and in Europe. However, only large firms can afford it and the experience is limited to a small number of people. The majority of Japanese firms and researchers have little experience of working with foreign partners.

Another indication of Japanese R&D's limited internationalization is that the percentage of internationally co-authored papers is lower in Japan than in the U.S. and in

European countries as indicated in Figure 9.

Figure 9: Trends in the international co-authorship ratio by country



Source: NISTEP (2004) p.165

Whatever may be the main reason for the limited internationalization of Japanese R&D, it is certainly a disadvantage for Japanese firms to have limited experience in dealing with foreign firms. This is particularly true in the area like ICT where standards are critical factor of competitiveness.[9]

4-3 Insufficiency of R&D supporting services in Japan

As mentioned above, Japanese firms are more inclined to technological self-sufficiency than to division of labor in R&D. They are less exposed to transactions with foreign firms than their European or American counterparts. Start-up companies were much less active in Japan. All those factors lead to the insufficiency of R&D supporting services in Japan. Most important of them are legal, accounting and personnel services.

Because of limited number of formal licensing activities and starting up of companies or buying out of these companies by larger firms, demand for the services associated with these activities was low. But, as advanced legal and accounting knowledge as well as experience in personnel affairs are indispensable to a successful cooperation or

[9] For the importance of standards in ICT, see for example, Chesbrough (2003), Gewar and Cusumano (2002)

strategic alliance, this is a serious disadvantage for Japanese firms.

5. Conclusions

Japanese R&D seems less efficient in 1990's than in 1980's. We examined, as reasons of this apparent deterioration, the emergence of radical innovations in 1990's and the increased need of division of labor in R&D. Japanese R&D was performed primarily by large firms that had strong inclination to secure a complete set of key technologies in-house rather than to specialize in specific technologies. Because those large corporations are not as quick in decisions as small firms and as they are less adapted to high risk, high return situations, they are less effective in early phase of radical innovation, where a number of trials and errors are necessary. The weakness of Japanese service sector resulted in relative inefficiency of ICT development in Japan and its less effective application. Limited internationalization of Japanese R&D is a serious problem when international division of labor becomes a necessary condition for successful R&D.

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