National Innovation Systems of Biotechnology in Japan and Korea

Abstract

By employing Bartholomew's model of national biotechnology innovation system (1997), this paper analyses the national innovation systems of biotechnology in the context of Korea and Japan to identify the important factors influencing the stock and flow of scientific knowledge in the process of innovation. In both countries, the public sector is the major player in the generation of scientific knowledge and technology transfer to bio-industries due to the lack of commercial orientation of the academia, the lack of mobility of scientists belonging to public research institutes, and the low level of university spin-offs. R&D activity for market-induced applied research is conducted mostly by the large established firms (biopharmaceuticals) rather than New Biotech Firms (NBFs) due to the low availability of venture capital. Japan lags behind even Korea in terms of the number of NBFs and venture capital investments in life sciences. Inter-firm cooperation is the main channel for accumulating scientific knowledge and facilitating technology transfer. The weak university-industry relationship in biotechnology is a more serious problem in Korea due to the lower level of R&D capability of universities still focusing on learning and mastering the extant knowledge. Therefore, institutional reforms that promote triple helix cooperation (State-University-Industry) are required to enhance the stock and flow of scientific knowledge in both Korea and Japan.

1. Introduction

Scientific and technological innovation capability has been recognised as the significant source of the industrial and economic growth. Many studies have underlined the importance of technological capabilities and national innovation system for the growth in terms of economy (e.g., Freeman, 1995; Kobrin, 1995) and competiveness (e.g., Cantwell, 1989; Kogut, 1991; Porter, 1990). A number of studies focused on the specific technology advantage of a country or a firm in the different national institutional context (e.g., Bartholomew, 1997; Dosi et al., 1990; Shan and Hamilton 1991; Lundvall, 1992). From the institutional perspective, national institutions that support the creation of new sources of research and technology capabilities in targeted industries help generate comparative advantages of a country (also see Etzkowitz and Leydesdorffr, 2000; Ziegler, 1997). The National Innovation System (NIS) perspective provides the understanding of why cooperative and strategic actions specialising technological sectors in targeted fields varies across countries. For example, Japan has long focused on the progress of biotechnology to catch up with American biotech R&D while Korea has largely invested in the development of ICTs, rather than other high-tech sectors in building national competitiveness.

Specific institutional framework of a country has serious implications for the trajectories of high-tech industries, notably biotechnology because of its different characteristics from other manufacturing technology sectors. Biotechnology can be distinguished by the high dependence on basic scientific research compared with other technology industries (i.e., automobile and semiconductor) and its close ties with market-induced apply research (Mowery and Rosenberg, 1993; Lehrer and Asakawa, 2004; Casper and Kettler, 2001). Therefore, biotechnology innovation brings about the large reform of NIS and the revision of existing S&T policies to support the commercial applicability of basic scientific research. Biotechnology is widely applied to create commercial products in various fields of industry, including agricultural, chemical, pharmaceutical and environmental fields (Kenney, 1986; Shan and Hamilton, 1991).

This paper examines important factors affecting innovation capabilities in newly-emerging, knowledge-intensive industries such as biotechnology with the analysis of the country-specific institutional framework that shapes the NIS. For that, I employed Bartholomew's model of national innovation system of biotechnology in the context of East Asia countries, with particular attention to Japan and Korea. Bartholomew (1997) indentified eight determinants of national innovation system of biotechnology which directly affect the stocks and flows of scientific knowledge: "tradition of scientific education; patterns of basic research funding; linkages with foreign research organisations; degree of commercial orientation of academia; labour mobility; venture capital system; national technology policy; and technological accumulation in related industrial sectors" (Bartholomew, 1997; pp.246).

Japan is one of the world largest countries with the US, Germany and the UK in terms of R&D investments in biotechnology innovation. In Japan, the long economic recession and slowdown of international competiveness since the late 1980s bring about R&D reforms and institutional change to create new frontiers and build up internationally competitive high-tech industries in strategic sectors, like biotechnology (Noland, 2007; Watanabe, 2000). For the advance of science and growth of bio-industry, Japan's government has removed the barriers to attract the world top foreign research institutes and firms, promoted start-ups, and built up research and industrial parks related to biotechnology (Whitley, 2003; Lehrer and Asakawa, 2004). Regarding biotechnology sectors, the traditional biotechnology products have the large share of the total domestic production of biotechnology firms. It includes traditional fermentation, cultivation, mutagenesis and pollution treatment technology. Biotechnology firms are active in the food or drink manufacturing sector, followed by the pharmaceutical manufacture (OECD, 2006).

It is no doubt that the USA innovation system of biotechnology is modelled for Japanese R&D reform and innovation of biotechnology, and then the Japanese rapid catch up motivates the newly industrialised countries (i.e., Korea, Taiwan and Singapore) to reform the national institution and reorganise R&D programme supporting biotechnology. Korea has emerged as the key player in global biotechnology market. In the early 1980s when chemical and genetic engineering emerged as the national economic growth sector in developed economies, Korea started to recognise biotechnology as an important discipline to strengthen industrial competitiveness and level up the national technology capabilities (Kim, 1997; Kim and Nelson, 1999). Entering upon the 1990s, the national Science and Technology (S&T) policy included biotechnology as one of the key strategic technologies with the high priority of the R&D investment. Under the special law on promoting biotechnology, a number of biotechnology-related research institutes and firms were established in this period (Rhee, 2003). Although it was almost ten year later than Japan, Korea has achieved the rapid catch up of biotechnology. Particularly, Korean has the present world-class capabilities in the areas of fermentation technology, antibiotics, diagnostics, and Hepatitis B vaccines (Rhee, 2003). The key bioindustry is the bio-food and biopharmaceutical sectors, which have the largest share of the total in terms of domestic production and employees (OECD, 2006)

There are many parallels between Japanese and Korean innovation system of biotechnology. In both countries, the public sector including the national funded universities and government-sponsored laboratories, rather than the private sector, is the major player in the generation and diffusion of scientific knowledge, and technology transfer to bio-industry because the majority of star scientists belong to the public institutes under the restrictive system for their mobility that limits to move into and work with the private sector (Park, 2004; Lehrer and Asakawa, 2004). The immobility of resources related to biotechnology causes the weak triple relationship (State-Academia-Industry) in both countries. The inactive inter-collaboration (e.g., cooperative patenting and joint R&D) is the more serious problem in Korea than Japan because of relatively weak innovation system of biotechnology (Castells and Hall, 1994; Rhee, 2003), which could make Korea to delay the catch-up of biotechnology with the United States and Japan. Regarding biotechnology R&D, the established firms have the large share of the total R&D spending over the biotech ventures in both countries because of the low availability of venture capital, whereas biotech entrepreneurs or new biotech firms originated from university spin-offs have greatly contributed to the development of bio-industry in the United States (Bartholomew, 1997). The venture capital investments in life sciences in Japan are smaller than those in Korea (OECD, 2009) which indicates lower availability of venture capital in Japan.

Therefore, in order to analyse whether the innovation system of biotechnology is adequate to meet the sustainable growth of Japan and Korea, and the evolution of S&T policies and R&D reforms supporting biotechnology are discussed after following the analysis of biotechnology characteristics. Also I critically analyse the specific institutional framework that shapes the national education and research systems in Japan and Korea by comparing with the United States.

2. Biotechnology Characteristics

Biotechnology refers to the application of microorganisms, such as a bacterium, virus and parasite, into the production of goods and services (Bartholomew, 1997). Broadly, the biotechnology could be divided into four fields of engineering - genetic engineering, cellular engineering, embryonic cell engineering and enzyme engineering. With utilisation of useful properties of living organisms, the general aim is to make more abundant and comfortable human life, for example, for the longevity, dietary life improvement and prevention or cure of diseases including incurable and hereditary diseases and so on (Shan et al., 1994).

Compared with other sectors of industrial technology (i.e., automobiles, textiles, shipbuilding etc.), the biotechnology more heavily relies on basic scientific research, thus academic scientists and scientists at biotech firms have the pivotal role in the development (McMillan et al., 2000). In order to the productive use of them, a close linkage between basic research and market-induced apply research exits in biotechnology innovation process (Mowery and Rosenberg, 1993), which is burred the traditional classification of basic research and applied research. The biotechnology development is realised by *"the product of the accumulation of scientific knowledge in research institutions and firms (stock) and the diffusion of the knowledge between them (flows)"* (Bartholomew, 1997: 266).

With these characteristics, the biotechnology is widely applied in various fields of industry, including agricultural, chemical, pharmaceutical and environmental protection, for industrial and commercial value creation (Kenney, 1986; Shan and Hamilton, 1991). However, the biotechnology involves in the high level of technological uncertainties and continuous controversy on the bio-ethics in the commercialisation process (George et al., 2001; Bartholomew, 1997).

3. National Biotechnology Innovation System

The pattern of biotechnology innovation and the level of its development are significantly affected by the distinctive national institutional context that includes scientific education system, venture capital system, research funding system, and government regulation related to resource mobility (e.g., labour, capital and technique) and international partnership with R&D institutions (see Kenney, 1986; Bartholomew, 1997; Mowery and Rosenberg 1993;

Shan and Hamilton 1991).

As the important institutional factors influencing on biotechnology progress, firstly, the national education system to progress the areas of science and engineering, particularly life science for biotechnology, has the pivotal role in accumulating, disseminating and creating knowledge in the process of innovation (Kenney, 1986). The development of scientific education institution affects the increase of a number of scientists and engineering and the elevation of their research skills (also see Bartholomew, 1997).

Secondly, the national funding of basic research that sponsors academic scientists and research laboratories provides the opportunity of learning and generating new scientific knowledge. It covers all machinery and materials necessities of research and development because of immense expenses of equipments, which is particularly continuous with biotechnology innovation (Mowery and Rosenberg 1993; Shan and Hamilton 1991).

Thirdly, the availability of venture capital that funds start-up firms has the crucial factor for scientific advance and the subsequent technological progress. The venture capital induces individuals including scientists to establish their own firms related to biotechnology, which facilitates scientific knowledge diffusion and spillover from research institutions to industry (Bartholomew, 1997). The biotech start-ups exploit and develop new techniques in a particular production with the process of learning before doing, not learning by doing, which is the process of transitional product innovation (Pisano, 1996).

Furthermore, the mobility of human resources, and networks of relationships between research institutions and industry have the significant role in knowledge accumulation, diffusion and transfer in biotechnology innovation. As the primary source of USA biotechnology advantage, close ties between industry and academic community, and mobility of scientists have been highlighted in many literatures (e.g., Blumenthal et al., 1986; Mowery and Rosenberg, 1993; Lethrer and Asakawa, 2004). The mobility allows academic scientists to start up their own companies or work in private science-based ventures, which is different from Japan and Germany where the movement of scientists are limited by public-sector regulations (Lethrer and Asakawa, 2004). For example, Blumenthal et al., (1986) underline the advantage of inter-collaborative research activities between university and biotechnology firms. In the empirical study of USA biotechnology, they found that patent applications in biotechnology firms linked with universities are almost four times as many as the independent firms, who do not collaborate with research institutions.

Fourthly, the removal barriers to share knowledge and exchange expertise across industries and countries have influence on the advance of scientific technology (Porter, 1990). In order to accumulate knowledge and transfer technology, the promotion of collaborative activities within (or between) firms and alliance with firms across the border are important items for any innovation process. Shan et al., (1994) empirically examine the relationship between the collaboration of US biotechnology firms and patent creations, and conclude the inter-firm collaboration positively affects the increase of innovation output. In transaction cost economies and resource-based views, the benefits of inter-firm relationships are often mentioned in many literatures. The relations allow firms to accomplish economies of scale and scope, efficient allocate and utilize resources, lessen risk, and share intellectual assets (Contractor and Lorange, 1988; Powell et.al., 1996). In biotechnology innovation process, inter-firm relations are formed mainly between large pharmaceutical firms and small biotech firms. The relations enable them to quickly acquire the emerging scientific knowledge with multifarious approaches and efficiently allocate R&D resources. Also, as biotechnology involves in the high level of technology uncertainty, inter-firm relationships allow the diversification of risks (George et al., 2001).

Finally, the cross-border R&D and international collaboration among firms and research institutions may allow local firms to bring in the additional profits beyond the obtained from domestic innovation. It provides the opportunity to acquire foreign countries' resources, including specialised knowhow and distinctive technology capabilities that are built and developed through the different national innovation system (Shan and Hamilton, 1991). In particular, the successful biotechnology innovation can be attributable to a good partnership with foreign institutions (i.e., universities and government laboratories) where hold specialised knowledge that allows complementing the existing one and thereby generating new discoveries (Shan and Hamilton, 1991).

4. Weaknesses of Biotechnology Innovation System in Japan and Korea

The current state of Korean and Japanese biotechnology progress is attributable to the rational R&D reform of innovation system which allows them to cover weaknesses that impede the stock and flow of knowledge. In this section, I will critically analyse the weaknesses the underlying of biotechnology innovation system in Korea and Japan by comparing with the innovation system in the United States.

The first is the underdeveloped national education system. Knowledge-creating institution, namely university, is one of the important actors in the innovation system of biotechnology not to only cultivate highly skilled manpower, but also participate in new product and innovation process. The recent thesis of Triple Helix has highlighted the important role of university in new-emerging technology innovation, such as biotechnology and ICTs (Etzkowitz and Leydesdorff, 2000; Leydesdorff, 2006; Marques et al., 2006), which is analytically different from the NIS model focusing on the central role of firms in technical innovation (Ludnvall, 1992) and the Triangle model focusing the decisive role of government in tradition (Inzelt, 2004).

Biotechnology innovation places importance on university capabilities in increasingly knowledge-intensive societies. The main task of university is to make close relationships between its faculty members and firms for the efficient knowledge transfer and active R&D cooperation (Etzkowitz and Leydesdorff, 2000). Also, universities are required to set up small business assistance programmes supporting venture business and spin-offs for the dynamics of innovation (also Castells and Hall,1994; Oh, 2002). In both countries, the national education system has long focused on the development of expertise in the field of science and engineering, however, the higher education concentrated on learning and mastering the extant knowledge over research based on creativity or originality (Bartholomew, 1989; Westney 1993; Oh, 2002).

The government encouraged the study of scientific engineering by providing many jobs for the graduates in research institutions, but the public funding of basic research was characterised by the lower amount and inefficient allocation compared with other technological advanced countries. The allocation of research funding in both countries was directed by the myopic approach based on seniorities rather than merits, which obstructs the build of autonomous research capabilities (Harayama, 2001; Odagiri and Goto 1993). Also, the research funding was concentrated on the publicly funded national universities. The most university R&D is conducted by the publicly funded national universities in Korea and Japan, while private top universities are the main player in the USA research development (Kneller, 2003; Rhee, 2003).

The second is the weak inter-linkage of research institutes and firms. The weak relationship between the public sector and the private sector in both countries may be, because of the traditional trend to belittle the commercialization of academic research, which causes the low availability of venture capital. The close linkage of State-University-Industry is the important factor to be a success in biotechnology innovation. The positive effect of R&D networking among R&D institutes, and partnerships with biotech-related organisation, including venture firms and hospitals on the innovation of biotechnology have been underlined in many existing empirical studies on innovation (Zucker and Darby, 1995; Powell et al., 1996; DeCarolis and Deeds, 1999; Nilson, 2001). R&D inter-collaborations among State, university and industry were relatively inactive compared with the USA, where there has been a considerable knowledge transfer from universities and government laboratories to industries (Branstetter and Ug, 2004; Motohasi, 2005). The inter-linkage between domestic organisations in Korea was much lower level than even Japan due to relatively feeble scientific and information networks, which leads delay the progress of biotechnology in Korea (Castells and Hall, 1994).

The third is the low availability of venture capital, low quality of entrepreneurships, and low turnover rate of labour including scientists across industries and research institutions (Ergas, 1987; Bartholomew, 1997; Rhee, 2003). These could be derived from the problem that the top scientists and academia at the national university were historically prohibited to engage in own business and work with the private firms as the partners (Lehrer and Asakawa, 2004). Also, since the majority of scientists and researchers belonged to the public sector with the position of public officer who undertake an assignment to produce public goods, such as energy, life science venture capital investment, spin-off and entrepreneurial process related to biotechnology were limited in Korea and Japan (also see Whitley, 2003, Kneller, 2003). Regarding venture capital investments in life science, Japan was still lower level with US$ 73 million, than even Korea (US$ 77.5 million) in 2007 (OECE, 2009).

In Japan, the unique institutional context may be fundamentally attributable to her socio-cultural system, such as collectivist culture and risk aversion nature of society. By contrast with the individualism characterised by the Anglo-American countries, the collectivist culture in Japan values trusts and long-term relationship, and thereby attaching a great importance to groups' interests relatively to individual ones (Lee and O'neill, 2003), which is similar characteristics with Germany.

This perspective could accommodate the different path of biotechnology innovation. That is, Japan addresses the inter-firm cooperation as the important factor influencing the capacity of biotechnology whereas venture capital or entrepreneurship is the engine of biotechnology progress in the United States (Bartholomew, 1997). In the United States, high-tech entrepreneurial process or New Biotech Firms (NBFs) through spin-offs emerged in the 1970s. In the late 1980s, the NBFs started to enter into strategic alliance with incumbent firms and research organisations for the commercialisation of discoveries (Jung et al., 2007).

In both countries, biotechnology R&D is mainly performed by the established firms due to the low availability venture capital under the uncertainty of biotechnology commercialisation (Henderson et al., 1999; Shin, 2001). Particularly, in the absence of biotechnology-related resources, Korea's government encouraged large domestic firms to learn scientific technologies and undertake biotechnology businesses through the channels of joint-R&D and strategic alliance with biotechnologically advanced foreign firms and research institutions since the middle of 1990s (Jung et al., 2007).

5. Reform of Japan's Biotech Innovation System

Biotechnology brings about the revision of existing S&T policies and reform of national innovation system because of the incompatibility of the existing technological institutions, which retards the commercialisation of basic research because of the public sector-orientated system of education and research in Japan. Beyond developing the commercial applicability of basic scientific research, Japanese innovation system leads the broad reforms of R&D system for competitive advantage in high-tech intensive sectors, and the reorganisation of ministries and government agencies related to science and technology to improve the efficiency for policy-making and implementing.

On the whole, the existing scientific technology policy has been reviewed to complement the vulnerabilities the underlying of national innovation system in Japan. The function of government has been extended to reduce or remove legal and culture barriers to promote dynamic innovation, which was proposed by the Second Science and Technology Basic Plan launched in 2001. The Second Science and Technology Basic Plan (2001-2005) aim at; (i) making competitive R&D environment; (ii) establishing R&D evaluation system based on fairness and transparency; (iii) improving R&D management; (iv) building the properly operational University-Industry-State relationships; (vi) promoting technology transfer to the private sector; (v) increasing small and medium innovative firms (vi) international technical tie-up (MEXT, 2003; Noland, 2007; Hane, 2002).

In order to make competitive R&D environment, the laws supporting merit-based salary, rather than the seniority, and the administrative autonomy of public research institutions, which allows national universities and public laboratories convert into self-governing Independent Administrative Institutions (IAIs) (Lehrer and Asakawa, 2004). Also, there has been integration of diversified parts of government R&D labs in Japan (Harayama, 2001)

The academic research system has been changed from only learning Western scientific knowledge to building up the originality to generate new own discoveries by allowing academic freedom. For example, universities could work as a consultant in private companies, private companies could establish research facilities within the campuses, and the both could jointly conduct researches among them (Yamaguchi, 2008; Motohasi, 2005). Also, they acted as a training partner with the internship to foster high-quality human resources, which is the beneficial to the industry as well as the society as a whole.

The Japan’s innovation system based on Industry-University-State tripartite cooperation has been consolidated by revising the Law for Promoting Research Cooperation in 1998 and enacting the Law for Promoting University-Industry Technology Transfer in 1998 (Harayama, 2001). The technology transfer from universities to industries is mainly performed through tacit agreement and licensing contract between faculty members and private companies (Fujisue, 1998; Branstetter and Ug, 2004).

The Basic Plan II also underlines the creation of socially valuable technologies. Based on this, four areas of S&T are given the priority for R&D funding – life sciences, information and communications technologies, environmental sciences, and nanotechnology and materials (Harayama, 2001). Biotechnology is the element of the all targeted S&T areas mentioned above. However, Japanese biotechnology lags behind the American, thus there has been the biotechnology R&D reform in Japan.

The "Basic Policy toward Creation of Biotechnology Industry" established in 1999 to intensively industrialise biotechnology by reinforcing the foundation of biotech research and development as a major goal of 21st century. Quantitatively, the Basic Policy proposes (i) the increase of government budget for biotechnology; (ii) the increase of public funding for biologists, bioinformaticians and other scientists related to life science; (iii) the increase of venture capitals and biotech start-ups by enlarging financial supports of government agencies (Harayama, 2001; Kneller, 2003; Lehrer and Asakawa, 2004). Most notably, the promotion of biotechnology start-ups was an essential particular because a very small minority of entrepreneurs were competitive and innovative in the bioindustry of Japan. Table 1 presents the percentage of biotechnology patent creation by sectors. The established firms had the largest share of total patenting in Japan, at 86 per cent whereas the major actor was start-ups in the United States. The patenting of New Biotech Firms (NBFs) in Japan and Germany were very lower numbers, only 3 per cent of the total, compared with those in the Anglo-American Countries characterised by the market-based individualism.

Table 1
Percentage of Biotech Patents by Research Institutions and Industry, 1987-1993

	Start-ups Firms	Established Firms	Universities, Gov. Laboratories
USA	40.4	38.2	20.7
UK	23.7	44.7	31.6
Germany	3.0	80.0	17.0
Japan	3.1	86.9	10.0

Source: Compiled by the data from Henderson et al. (1999).

Qualitatively, the network of relation between academia, scientists and entrepreneurs is underlined to coordinate basic scientific research and applied research to swiftly commercialise research results (Lehrer and Asakawa, 2004). The freedom of university scientists is guaranteed by setting up a number of legal institutions. It allows academia at national university to hold patent rights, work in the private sector, and found their own venture companies in order to develop and commercialise their discoveries (Also see Kneller, 2003).

Along with domestic reforms, Japanese government has promoted the cross-border biotechnology R&D and strategic alliances with firms and research institutes from technological advanced countries. In the absence of basic science foundation, the government has sent a number of domestic scientists to the USA, rather than local doctoral programmes (Saxonhouse, 1986), as well as encouraged Japanese firms to invest in the US universities to develop life science and its commercial application (Westney, 1993; Lehrer and Asakawa, 2004). These render great services to the accumulation of external knowledge, notably basic molecular biology research, and the transfer of knowledge into domestic research institutions and firms (Bartholomew, 1997).

At the firm level, Japanese biotechnology firms have entered into strategic alliances and the partnership with foreign research institutions and firms, mainly in the United States in order to acquire the USA advanced research and technical skills (Bartholomew, 1997). The objectives of targeting the United States are to exploit the nation's specified knowledge and techniques, as well as learn adaptability and applicable capabilities that allow the translation of scientific knowledge into commercial products (Shan and Hamilton 1991, Saxonhouse 1986). It is a strikingly different aspect from the USA biotechnology firms that make the cooperative agreement with foreign firms to raise funds for projects that involve in a large investment, a time-consuming and a high risk. As a result, there have been substantial knowledge flows scientific knowledge and technology from the United States to Japan (Bartholomew, 1997), which may give the foothold in developing own inventive products and thereby becoming a significant competitor to the USA in biotechnology innovation.

Table 2
Number of biotechnology alliances, the Triad, 1990 to 2006

	1990	**1992**	**1994**	**1996**	**1998**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
USA	28	77	125	141	120	165	274	219	274	277	358	360
Europe	26	61	95	101	81	91	171	177	178	197	217	280
Japan	6	8	11	20	11	9	17	41	28	32	54	53
Other	11	11	12	20	6	22	48	56	52	50	75	96
Total	45	98	161	177	147	200	355	332	368	389	481	526

Source: compiled by the data from OECD biotechnology Statistics, 2009

Table 2 present the increase numbers of strategic alliances by domestic and multinational firms for technology transfer or joint research in biotechnology in Japan. The 120 biotechnology alliances were formed in the 1990s, and it reached a peak in the early 2000s. Although the largest numbers was for alliances involving firms from the United States, the share of alliances involving Japanese firms steadily increased after 1990.

In the sectors of biotechnology, traditional biotechnology products (i.e., traditional fermentation, cultivation, mutagenesis and pollution treatment technology) accounted for a great part of total domestic production of biotechnology firms, while modern biotechnology products (i.e., recombinant DNA, cell fusion, tissue culture and biomimetic technology) had the small share of the total (OECD). Table 3 shows that traditional biotechnology and modern biotechnology products constituted 82 per cent (PPP$ 45,623 million) and 18 per cent (PPP$ 9,886) respectively. Food products accounted for 62 per cent of total domestic production of biotechnology firms, followed by pharmaceuticals, diagnostic reagents and medical instruments (20 per cent) and chemical products (6 per cent) in 2003. In the Japanese bio-industry, the majority of biotechnology firms worked in the food or drink manufacturing sector in 2003, at 20 per cent (242 firms). The chemical industry was second, at 11 per cent (127 firms), followed by the pharmaceutical manufacture (20 per cent). In 2003 1,162 firms were active in the biotechnology industry of Japan (OECD, 2006).

Table 3
Japanese Biotechnology Production of Firms, by Biotechnology Sector, 2003

	Total	Traditional %	Modern %	Share of total Production %
Foods	36,132.2	98	2	62
Pharmaceuticals, Diagnostic Reagents & Medical Instruments	11,296.2	49	51	20
Chemical Products	3,165.2	51	49	6
Environment-related Equipment & Facilities	1,497.9	90	10	3
Tech. Support and Services	1,057.7	34	66	2
Equipment and Facilities for Research & Production	460.5	24	76	1
Agriculture-related	449.5	87	13	1
Bioelectronics	252.0	100		
Livestock & Fisheries related	232.7	70	30	
Research Samples & Reagents	206.5	37	63	
Data Processing	127.5	28	72	
Fiber & Fiber Processing	19.0	56	44	
Other Products	606.9	89	11	6
Total	55,512.6	82	18	

Source: Compiled by the data from the Japan Bioindustry Association (JBA) and OECD.

Furthermore, there has been a great effort to solve the coordination problem among ministries and government agencies related to science and technology, including the Ministry of International Trade and Industry (MITI), the Science and Technology Agency (STA) and the Ministry of Education (ME). The coordination problem has the harmful effect on the creation of new industries, such as biotechnology, the "General Science and Technology Council (STC)" was built in 2001 as the remedial measure, by the structural reform of previous the "Science and Technology Council". The STC acts as a consultant and a coordinator for S&T policies to implement efficiently (MEXT, 2003). Also the ministries and government agencies related to technology were reorganised to successfully design and carry out S&T policy in Japan, for example, the Ministry of Education, culture, Sport, Science and Technology (MEXT) was organised by unifying the STA and ME in 2001, which covers a wide range of S&T fields including life science, social sciences and humanities (also see Harayama, 2001).

6. Reform of Korea's Biotech Innovation System

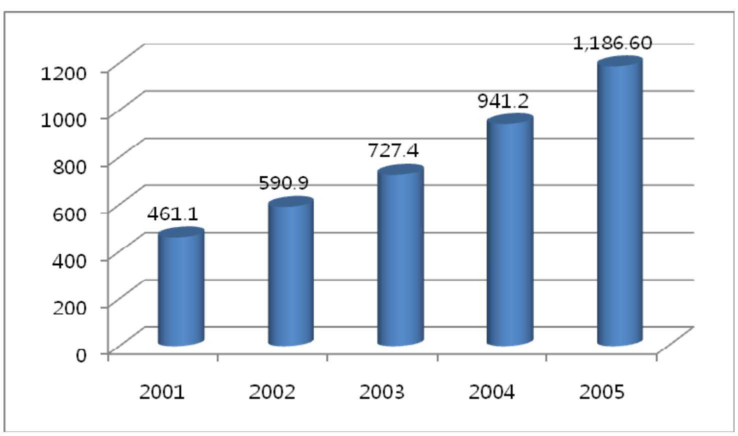
In the early 1980s, Korea started to add the technologies related to biotechnology to the national S&T plan with the promulgation of the "Genetic Engineering Development Act" (1983) and the "Biotechnology Promotion Law" (1983), which formed the groundwork for building up innovation capabilities of biotechnology (Jung et al., 2007). Under these laws, the Research Institute of Bioscience and Biotechnology (1985) by spinning off from the Korea Institute of Science and Technology (KIST) and the Bio-industry Association (1991) were established since (Rhee, 2003). Entering upon the 1990s, biotechnology was selected as one of the national strategic technologies in the high-tech fields, including ICTs and nanotechnologies, to catch up with the USA, Germany and Japan. It brought about the large reform of education system to foster talents, promote spin-offs and facilitate R&D cooperation with biotechnology firms. Korean universities started to establish biotech-related department, industrial liaison and research centre in the early 1990s (Rhee, 2003).

Korea's government established the Highly Advanced National (HAN) Project in 1992. The HAN project included the bioengineering development programme to foster expertise and R&D investments in biomaterials, pharmaceuticals and agrochemicals. The HAN project dawn by the Ministry of Science and Technology (MOST) was broadly comprised by two items of technological development schemes, which was performed with US$ 3.2 billion investments during the period of 1992-2001 (MOST, 2007). One is the product technology development, focusing on the improvement of high-tech products capable to compete with advanced countries. The high-tech products include HDTV (High Definition Television), ISDN (Integrated Services Digital Network), ASIC (Application Specific Integrated Circuit), biomedical, micromachining and next-generation automobiles and so on. Another is the fundamental technology development for sustainable economic growth and harmonising the enhanced standard of living in future. The key items are the accomplishments of advanced environment technology, manufacturing systems, new energy, human sensibility ergonomics, and new-generation semiconductors and so on (MOST, 2007).

With the special aims of biotech R&D capabilities at the competitive level, the Biotech 2000 Programme established in 1994, which is a derivative of the HAN project. The main research areas were Biosensors, BIOMEMS, DNA microarrays, Bioinformatics, Nanobiotechnology, Antibody engineering, Anti-aging drug development, Neurobiology, Drug delivery system, Gene therapy, Carbohydrate engineering, Genomics & breeding technology for transgenic animals and plants (Rhee, 2003). Under this programme, Korea's government made the plan to invest US$ 15 billion for biotechnology development with a step-by-step process for 14 years: (i) building up the sound scientific foundation for autonomous innovation capabilities of biotechnology (1994 -1997); (ii) making the competitive R&D environment and making the properly operational University-Industry-State relationships for bio-products (1998-2002); (iii) reaching the world-class capability of basic scientific research and its commercialisation (2003-2007) (Rhee, 2003). In order to develop the world-class capability of biotechnology, Korean government increased in biotechnology R&D expenditures, accounting for 27 per cent of the average annual growth rate from 2001 to 2005 as shown in Figure 1.

However, Biotech 2000 Programme had the limitation to reach biotechnological capabilities at the targeted level due to the low availability of venture capital and home-grown talents, which led the birth of 21st Frontier Research Programme (Lee, 2000). With the large investment of US$ 3.5 billion, twenty R&D projects were undertaken under the 21st Frontier Research Programme by the year of 2002 (MOST, 2007). The main research areas in biotechnology sector are; (i) functional analysis of human, microbial and crop genomes; (ii) biodiversity of indigenous plants; (iii) stem cell biology and therapeutic applications; (iv) proteomics research; (iv) high throughput screening of novel compounds for bioregulators using structural biology and pharmacogenomics (Rhee, 2003).

Figure 1
Korean Government R&D Investments in Biotechnology, Million PPP$, 2001-2005



Source: complied by the data from Science and Technology Statistics from Korean Ministry of Education, Science and Technology.

The 21st Frontier Research Programme more strongly focused on improvement of expertise, inter-collaboration among State, University and Industry, joint-R&D with foreign research organisations, and venture business. Since the development of scientists and technicians in biotechnology was an urgent national priority, the government drew up the High Quality Human Resources Development Project by the reform of national education and training system (MOST, 2007). Regarding international cooperation, Korean biotech cooperation centres were constructed in foreign countries, for example, the Korea-UK Bioscience and Biotechnology Cooperation Centre in the Institute of Biotechnology of the Cambridge University and the Korea-China Bioscience and Biotechnology Cooperation Centre in the campus of Shanghai Research Centre for Life Sciences (Rhee, 2003). With the successful biotechnology policy, the bio-patent activity in Korea was drastically increased in the 21st century. Table 4 presents a number of actors and patents in Korean biotechnology industry over the years which divided into three periods by considering the evolution of bio-industry policy: 1985-1993, 1994-1999 and 2000-2004. However, the number of cooperative patents application was a very low level, accounting for 3 percent (407) of the total patents applied to the KIPO (13,387) between 2000 and 2004, which is the facing problem of Korean innovation system of biotechnology.

Table 4
A Number of Actors and Patents in Korea's Biotechnology Industry

	1985-1993	1994-1999	2000-2004	1985-2004
No. Firm	151	396	1,193	1,465
No. Universities	4	20	72	73
No. Public organisations	8	35	69	82
No. Patents applied	5,686	8,386	13,387	27,459
No. Patents applied by Korean	1,559	3,981	8,131	13,671
No. Cooperative application	65	151	407	623
No. Patents granted	3,004	4,243	2,221	9,468

Source: Jung et al. (2007). "The dynamics of the bio-industry: What is the main force for generating biotechnology by firms in the Korean technology system," DRUID Summer Conference 2007, Copenhagen Business School, Denmark, pp. 7

Table 5
Biotechnology Venture Capital Investments, OECD Countries, 2007

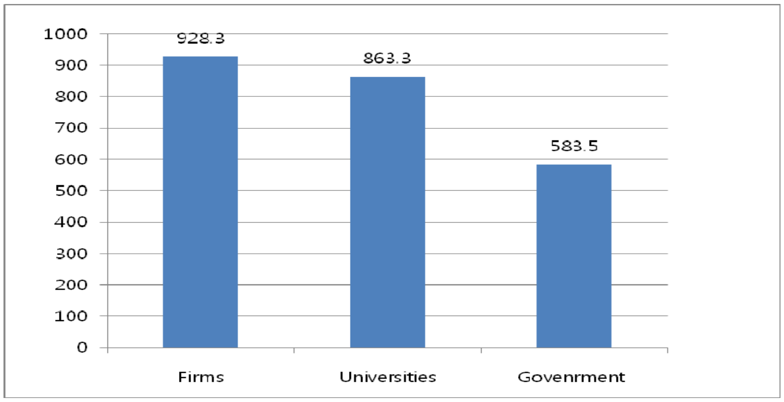
	Life Sciences		All Venture Capital	
	Total (million US$)	Average size per investment (thousand US$)	Total (million US$)	Average size per investment (thousand US$)
United States	5,507.0	10,255.1	30,885.9	8,110.8
Canada	523.3	6,460.9	1,702.3	3,724.9
France	483.1	2,268.2	1,802.1	2,130.1
United Kingdom	447.6	2,062.6	4,388.6	3,971.6
Germany	351.9	1,312.9	1,302.8	924.0
Sweden	299.5	1,081.4	811.2	1,139.3
Switzerland	167.4	4,184.6	622.2	6,549.4
Australia	140.8		1,104.0	
Belgium	121.9	3,584.4	431.2	2,613.4
Denmark	122.0	1,848.7	627.0	4,045.0
Spain	101.9	2,830.2	1399.4	5.280.7
Netherland	91.2	1,682.2	953.4	2,755.4
Korea	77.5	1,937.0	1,322.5	2,150.4
Japan	73.0	405.8	710.0	522.8
OECD	8,631.3	2,059.3	50,117.2	3,535.9

Note: the data of Japan is 2006
Source: compiled by the data from OECD biotechnology Statistics, 2009

In order to bolster up venture capital investments and new start-ups related to biotechnology, Korean government established the number of legal institutions bolstering up venture capital investments and new start-ups related to biotechnology, for example the "Act on Special Measures for the Promotion of Venture Businesses" (1997) and "Brain Research Enhancement Act" (1998) (Jung et al., 2007). With the great effort of government, Korean entered into the 13th highest in the total venture capital investment in life sciences with US$77.5 million, followed by Japan (US$73 million) while the average size was the 8th highest with US$1,937 thousand in 2007, after the United Kingdom (See Table 5). Considering the development of Korean economy, Korean had the highest share of GDP from venture capital investments in biotechnology.

For an active entrepreneurial process in the bio-industry of Korea, a number of bio-clusters in were established in the specific geographical areas. In the clusters, the related educational equipments and R&D institutes were constructed to be of benefit to firms located in the in the vicinity of the clusters (Kim and Ko, 1998). Regarding biotechnology R&D activities in Korea, combined, business enterprises, higher education and government research institutes spent PPP$ 2,375.1 million on biotechnology R&D in 2006. Figure 2 shows that firms had the largest share of total biotechnology R&D expenditure in 2006, at 39.1 percent, followed by universities (36.5 per cent) and public research institutes (25.4 per cent).

Figure 2
Korean Biotechnology R&D by Sector of Performance, Million PPP$, 2006



Source: OECD Biotechnology Statistics, 2009

Table 6
Korean Biotechnology Firms by Biotechnology Sectors, 2004

	Biotechnology firms and employment by application field		Production by field of activities
	No. firms	No. employees	Percentage
Biopharmaceutical	189	4,356	40%
Biofood	157	3,471	43%
Bioenvironmental	87	1,583	5%
biochemical	86	983	6%
Bioprocess & equipment	55	657	2%
Bioassay, Bioinformatics & R&D services	33	531	3%
Bioenergy and Bioresource	21	407	1%
Bioelectronics	12	150	
Total	640	12,138	

Source: OECD Biotechnology Statistics, 2006

In the Korean bio-industry, 640 firms were active in eight sectors of biotechnology in 2004: biopharmaceutical, biochemical, biofood, bioenvironmental, bioelectronics, bioprocess and equipment, bioenergy and bioresource, and bioassay, bioinformatics and R&D services (OECD, 2009). In the biotechnology sectors, biotech firms were active for the production in biofood (i.e., amino acids) with 43 per cent, followed by biopharma (40 per cent) and biomedical (6 per cent) as shown in Table 6. Regarding actors in bio-industry, 30 per cent of biotechnology firms (189 firms) belonged to the biopharmaceutical sector with the largest share of employees (4,356), followed by the biofood sector with 157 firms and 3,471employees. Over half of the Korean biotechnology firms were the small-sized with less than 50 employees (OECD, 2006), however the large established firms (e.g., LG Chemical Ltd. and SK Chemical Ltd.) have played the leading role in biotechnology R&D and innovation process (Rhee, 2003), which is contrastive to the United States. The USA advanced biotechnology is attributable to new start-ups which had been founded by venture capitalists, large incumbent chemical/medical firms and researchers related to biotechnology.

7. Conclusion

This paper has examined some weaknesses underlying the biotechnology innovation system in Japan and Korea, and their institutional reforms to compensate for the defects that impede the stock and flow of scientific knowledge. In particular, important determinants of biotechnology progress in the context of the two East Asian countries have been analysed by employing the Bartholomew's model of biotechnology innovation system. In absence of science base, particularly life sciences, there have been active cross-border activities to acquire, share, diffuse and transfer scientific knowledge and techniques in Japan and Korea.

In order to build up and develop the capabilities in both basic scientific research and market-induced apply research, the countries have established biotechnology cooperation centres as well as entered cross-border R&D alliances and partnerships with foreign research institutes and firms related to biotechnology. The Unities States, the United Kingdom and Germany are targeted to acquire and share the need of biotechnology resources, including human capital. In both countries, the inter-firm cooperation is the main channel of biotechnology innovation to accumulate scientific knowledge, generate discoveries and improve them. Compared with biotechnology innovation system the United States, the triple cooperation is very weak because of low availability of venture capital, low mobility of labour and low degree of commercial orientation of academia. University lacks the capabilities to develop scientific knowledge, foster creative talents and perform joint-R&D, which lead the low quality of entrepreneurships and inactive spin-offs in the countries.

In Japan, Biotechnology R&D is performed by mainly established firms (biopharmaceuticals), which is the similar characteristics of Korean innovation system, but the different aspect of the NBFs-based innovation system in the United States. Although a number of biotechnology start-ups have been markedly increased by financial supports from several ministries under the Science and Technology Basic Plan II, Japan still lag behind the USA, the UK and even Korea in terms of the numbers of the biotech firms and venture capital investments in life sciences. This is attributable to her socio-cultural system, such as collectivist culture that causes the lower mobility of labour and less availability of venture capital compared with the Anglo-American characterised by individualism.

Although Japan has carried out the radical reforms of biotechnology and gradually enhanced the increase of biotech star-ups, mobility of human resource and cooperation between academia and business by setting up various public measures, the problems are still incompletely resolved. With regard to university-industry partnership, most licenses and joint researches to develop new biotechnology are formed by the cooperation with external research institutions and venture firms, rather than domestic organisations. Also, star scientists are still limited to move in the private sector in the institutional context despite the law permitting administrative autonomy of public research institutions has been enforced, which allows the national universities and government labs to move the Independent Administrative Institutions (IAIs) (Lehrer and Asakawa, 2004). Therefore, Japan should devise the mechanism to enhance the mobility of academia and scientists at the national research institutions and facilitate university spin-offs. Also, Japan should consider other factors capable influencing biotechnology innovation for sustainable competitive advantage, because not only start-ups and freedom of academia movements always bring about the large flows of scientific knowledge and the newest technology.

On the other hand, Korea has achieved the rapid growth of biotechnology development by the successful reform, particularly fermentation technology, antibiotics, diagnostics, and Hepatitis B vaccines, which are the internationally competitive levels (Rhee, 2003). Korean government established a number of biotechnology development programmes to promote technology transfer, joint R&D, spin-offs and high-tech entrepreneurial processes for the commercialisation of basic scientific results. The participants are privileged from the monetary burden of R&D with a number of incentives, such as research funding, tax detection for intellectual resource trade, low interest loans for the construction of the R&D facilities, subsidies for human capital and so on (Chun, 2002; Lee, 2000).

However, there are the small numbers of biotech venture business originated from private research institutes and the chance of survival is very low because of the monopolistic strength of large firms, which are the facing problem of Korea’s innovation system (Kim and Ko, 1998). Comparison with Japanese innovation system of biotechnology, there are more serious problems awaiting the solutions in Korean innovation system of biotechnology, which hamper the generation of competitive own bio-products, and thereby delay the catch-up with Japan. Those are, (i) the short of industrial manpower compared with researchers in the basic science that causes the imbalance of human resources; (ii) the immature financial market for the long-term R&D investment and venture capital, (iii) the lack of university spin-offs, (iv) the feeble scientific and information networks that causes inactive cooperation among State-University-Industry. The lower proportion of new start-ups spun off from universities and research institutions may be, because of the restriction and disallowance of individual researchers to utilise their research outcomes. Also, Korean universities are still focused on learning scientific knowledge, rather than fostering creative individuals, and thereby weakening the motivation to pursuit biotechnology innovation. Importantly, measures to establish the dynamic of biotechnology innovation system associated with active strategic alliances across the border and inter-collaboration among researchers and users of research are urgently needed in both countries, Korea and Japan. Therefore, the policymaker should devise the mechanisms to develop industrial talent, facilitate university spin-offs, and make close relations between academia and industry communities. Also, Korea should set up the concrete biotechnology strategy to efficiently utilise the existing intellectual assets and generate new discoveries for sustainable competitive advantage in the future responding to the ever-changing technology trends.

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