Biotechnology commercialization in the Republic of Korea

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Abstract

In a knowledge-based economy, biotechnology industry is considered as one of the key industry whose development is important for national competitive advantage. In the era of globalization, many national and local governments are eager to develop the biotechnology industry to build up the capabilities for the future of their economies. Based on a firm survey of the Korea Biotechnology Industry Organization in the biotechnology industry, recent trends in the industry were studied. Intellectual property-based finance were introduced to promote commercialization of biotechnology. Findings showed that SMEs participate actively in the Korean biotechnology industry and the venture capital investment in the biotech sector had been growing rapidly. Using intellectual property-based finance, SMEs could monetize their intellectual property more easily. This study provides meaningful information for decision makers in the biotechnology industry.

Biotechnology industry

Biotechnology is recognized as one of the most important industries in a knowledge-based economy (Kang and Park, 2012). Since Karl Ereky created the word 'biotechnology' in 1919 to refer to 'methods and techniques that allow the production of substances from raw materials with the aid of living organisms', biotechnology has been defined in many different ways (Kang 2009, OECD 1999). In OECD, biotechnology was defined as 'the application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services' (Kang 2009, OECD 2005).

Biotechnologies give rise to biotechnology industry when they are applied at industrial and commercial scale (Kang 2009, Sasson 2004). Because the scope of the industry is determined by biotechnology itself and is extended in accordance with technological development, biotechnology firms are not classified within a single industry in industrial classification systems (Kang 2009, KIET 2004). In Republic of Korea, a biotechnology industry classification system of eight categories has been used (KBIO 2017). Table 1 presents the structure of the biotechnology industry classification system in the Republic of Korea.

In the Republic of Korea, biotechnology initially began to develop in academia such as universities and research institutes in the early 1980s (Kang 2009, KIET 2003). The Republic of Korean government actively invested in the biotechnology industry during the 1990s and SMEs and large established firms began to actively participate in the biotechnology industry around the year 2000 (Kang 2009, KIET 2003). Biotechnology industry in the Republic of Korea had been growing rapidly with 21.52% CAGR (Compound Annual Growth Rate) during 1999~2004 (KIET 2007).

According to the report from KBIO, the domestic biotechnology industry has steadily progressed. The survey data on the biotechnology industry in the Republic of Korea showed that the Korean biotechnology industry had been steadily growing with 4.8% CAGR during 2012~2016 (KBIO 2017) (Table 2). Total size of domestic supply in 2016 was 8.9 trillion won and total size of domestic demand was 5.9 trillion won (KBIO 2017). The biopharmaceutical Industry is the largest sector and the biofood industry is the next largest one (Table 3).

Biotech SMEs

In the biotechnology industry, one of high-tech industries, start-ups and small firms play a crucial role in the advancement of the industry (Audretsch 2001, Giesecke 2000, Kang and Park 2012). The size of the firm is what is most contrasted in many literatures since Schumpeter's contrast results. Schumpeter (1934) argued the small-scale entrepreneur was the key of capitalism's vitality (Schumpeter I) but later he saw the large-scale enterprise as the principal innovator (Schumpeter II)

Table 1: Structure of the biotechnology industry classification system in Republic of Korea

Categories	Name of industrial classification
Goods	Biopharmaceutical industry Biochemical and bioenergy industry Biofood industry Bioenvironmental industry Biomedical equipment industry Bioinstrument and bioequipment industry Bioresource industry
Services	Bioservice industry

Source: KBIO 2017

Table 2. Size of production and domestic demand in biotechnology industry (2012-2016) (Unit: billion won, %)

Classification		2012	2013	2014	2015	2016	Annual average rate of change
Supply and Demand (Production + Import)	Investment amount	8,575.6	8,898.0	9,007.6	9,912.6	10,338.2	4.8
	Distribution ratio	10.6	3.8	1.2	10.0	4.3	
Production (Domestic sales + Export)	Investment amount	7,144.5	7,510.8	7,607.0	8,503.9	8,877.5	5.6
	Distribution ratio	10.5	5.1	1.3	11.8	4.4	
Domestic Demand (Domestic sales + Import)	Investment amount	5,528.1	5,733.7	5,602.4	5,626.6	5,892.6	1.6
	Distribution ratio	9.6	3.7	-2.3	0.4	4.7	

Source: KBIO 2017

Table 3: Size of production and domestic demand in biotechnology industry (Unit: million won, %)

Industrial category	Production		Domestic demand	
	Total	Distribution ratio	Total	Distribution ratio
Total	8,877,520	100.0	5,892,591	100.0
Biopharmaceutical industry	3,350,668	37.7	2,930,875	49.7
Biochemical and bioenergy industry	1,112,534	12.5	1,064,450	18.1
Biofood industry	2,918,164	32.9	1,229,242	20.9
Bioenvironmental industry	29,479	0.3	29,272	0.5
Biomedical equipment industry	587,645	6.6	120,689	2.0
Bioinstrument and bioequipment industry	124,582	1.4	118,713	2.0
Bioresource industry	170,241	1.9	154,081	2.6
Bioservice industry	584,207	6.6	245,269	4.2

Source: KBIO 2017

(Schumpeter 1942, requoted from Cohen and Klepper 1992, Kang 2009). Arguments exist both supporting a large size and a small size with regard to its effect on innovation performance (Galende and de la Fuente 2003, Kang 2009). Scholars studying small firms argued that they have a merit of 'greater flexibility, better communication, greater specialization possibilities, informal and strategic controls' and have the relative advantage in highly innovative industries (Acs and Audretsch 1987, Galende and de la Fuente 2003, Kang 2009).

In 2016, 57.7% of companies in Republic of Korean biotechnology industries belonged to 'less than 50 workers' and 29.1% of companies belonged to 'from 50 to 299' among total size of workers (KBIO, 2017) (Figure 1).

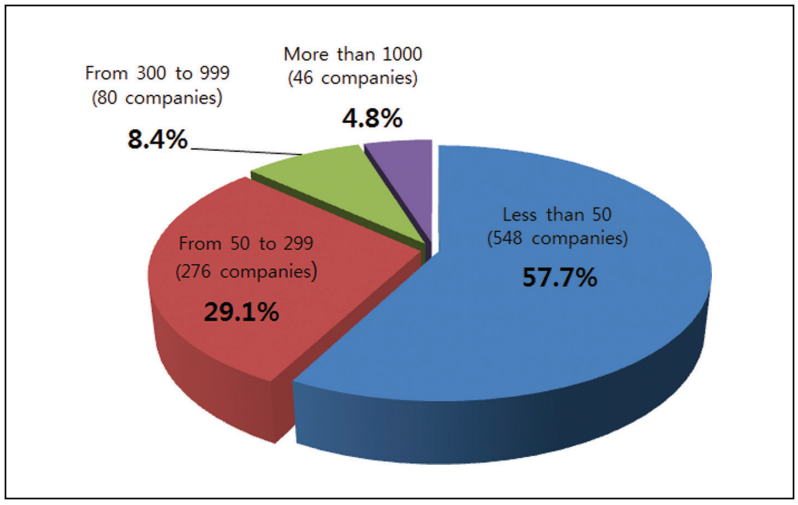
On the other hand, the biotechology industries are 'comprised of a value chain of highly interrelated but distinguishable activities' including R&D, clinical trials, evaluation, manufacturing and sales (Kang 2009, Szuhaj 2008).

When considering the main actors in each process, biotech SMEs are located at the hub of a network of upstream and downstream relationships (Table 4, Figure 2). Therefore, biotech SMEs serve as 'value-added intermediaries' between upstream partners (e.g. universities) and downstream partners (e.g. established enterprises), taking on 'a dual role of knowledge transformation and commercialization' (Kang 2009, Rothaermel and Deeds 2004, 2006, Stuart et al. 2007).

Collaboration (Networking)

In high-tech industries, where rapid scientific or technological developments have occurred, knowledge is broadly distributed that 'no single firm has all the internal capabilities necessary for success' (Kang 2009, Powell et al 1996). Many previous studies revealed that the correlation between innovation and interaction with other actors is positive (Baum et al. 2000, George et al. 2002, Hagedoorn 1993, Kang 2009, Romijn and Albaladejo 2002, Rothaermel and Deeds 2006, Shan et al. 1994). There are two groups of literatures to study effects of inter-firm partners in particular (Kang 2009, Stuart et al. 2007). One has been focused on connections between biotechnology firms and universities including public research institutes (Kang 2009) . The other has been focused on collaboration between biotechnology firms and established firms such as big pharmaceutical companies (Kang 2009). These interactions help firms to overcome deficiencies in their information, scientific knowledge, resources and competencies (Becheikh et al. 2006, Kang 2009, Kang and Lee 2008, Romijn and Albaladejo 2002).

Biotechnology firms maintain broad and deep interaction with universities



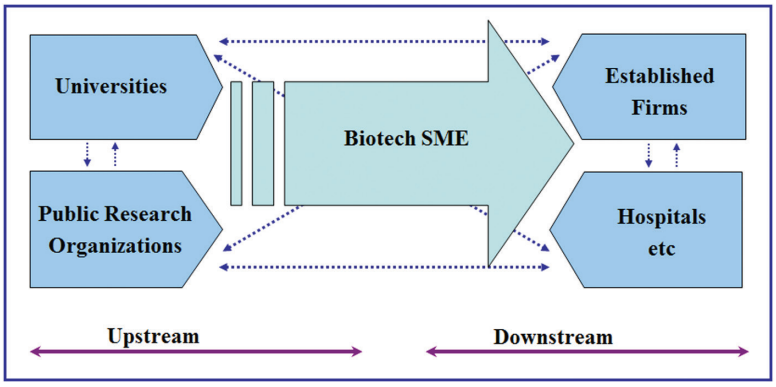
Source: KBIO, 2017

Figure 1: Korean biotechnology industries' distribution per size of workers

Table 4: Main actors in each value-chain in biotechnology industry

Value chains	Main actors
R&D (Basic) R&D (Application)	University, Research institutes Biotech SMEs, Large established firms
Clinical trials/evaluation	Research hospitals, Firms specializing in cliniclas
Manufacturing	Large established firms
Marketing	Large established firms

Source: Powell et al. 1996, Kang 2009



Source: Kang 2009, modified by author

Figure 2: Inter-firm networks of biotech SMEs

(Stuart et al. 2007). Zucker et al. (Zucker et al. 1998; Zucker et al. 2002; Zucker and Darby 2001) investigated co-authorships and argued that the dependence of new biotechnology firms on university science, in particular human capital like star scientists, ran so deep (Kang 2009, Stuart et al., 2007). George et al. (2002) found that companies with university linkages had higher levels of innovative output and Baum et al.'s study revealed that biotech startups which formed upstream alliances generally exhibited stronger performance (Baum et al. 2000, Kang 2009).

The strong complementary nature of biotechnology firms and established firms makes collaboration between established firms and biotechnology firms quite positive and supportive (Audretsch and Feldman 2003, Kang 2009). While new biotechnology firms are specialized in the certain types of knowledge, products and applications, large established firms 'have experience in large-scale production, marketing and distribution and the regulatory process required to bring products to the market' (Audretsch and Feldman 2003, Kang 2009). And procuring complementary assets through market exchange is apparently more efficient than the internal transaction (Audretsch 2001, Kang 2009). For these reasons, networks between biotechnology firms and established companies blew up in the mid-1980s (Cullen and Dibner 1993 requoted from Audretsch 2001 and Audretsch and Feldman 2003, Kang 2009). Baum et al. (2000) found that downstream alliances generally exhibited strong initial performance (Baum et al 2000, Kang 2009).

In Republic of Korean biotechnology industries, 29.6% of 980 companies have cooperative relationships with other organizations as of 2016 (KBIO 2017). The most frequently found type of cooperative relationship was 'joint R&D contract' (83.4%), followed by 'technical tie-up and licensing' (22.1%) and domestic and international technical manpower exchange (11.4%) (KBIO 2017, Multiple responses accepted).

By cooperating organization, the number of cooperation cases with Universities was frequently found (36.0%), followed by cooperation cases with business entities (35.6%), research institutes (21.9%) and medical institutes (6.5%) (KBIO 2017). The number of cooperation cases between a bioindustrial company with 1 - less than 50 workers and a university is large at 174 (KBIO 2017) (Table 5).

Kang (2009) examined the effects of domestic and international networks on firm's innovation and found that not domestic partnerships but foreign partnerships positively affected both domestic and global innovation performance. Physical proximity is less important and ICTs act as the material devices to help firms to communicate with partners in the distance (Kang, 2009). OECD's study also suggested that

Table 5: Cooperating organizations by scale of workers (Unit: Count)

Classification		Cooperative relationships in total	Business entities	Research institutes	Universities	Medical institutes
Total	Total	1,157	412	253	417	75
	1 – less than 50 workers	468	162	110	174	22
	50 – 299	392	131	72	155	34
	300 - 999	94	27	15	40	12
	1,000 or more	203	92	56	48	7

※ 1-less than 50 workers: 548 companies; 50-299: 276 companies; 300–999: 80 companies; 1,000 or more: 46 companies.

Source: KBIO, 2017

collaboration with foreign customers can help firms to develop new products, processes or other innovations (Kang, 2009, OECD 2008). It is needed to be linked with foreign entities to promote biotechnology industry in the Republic of Korea. However, firms must realize the many obstacles they are likely to confront before initiating international collaboration and try to obtain skill and sensitivity toward resolving the managerial challenges (Hergert and Morris 2002, Kang 2009).

Intellectual Property-Based Finance

Biotechnology industry is a science-intensive sector and innovative activities in biotechnology require strong R&D efforts to explore and explicit knowledge (Kang 2009, Mangematin *et al*. 2003, Orsenigo 1989). The intellectual property system provides incentives for R&D, particularly in fields where innovations have long gestation periods. Inventions and technological advances are the important source of economic growth and the legal systems for IP are needed to motivate inventors. The protection of research results becomes important in such research-based industry (Burron 2006). The legal systems enable innovative entities to earn financial benefit from what they invent by using intellectual property-based finance. Intellectual Property-based finance refers to any kind of financing on Intellectual property (Kang 2017). Venture capital investments, the credit guarantee system, and IP trust are major parts of IP finance (Kang 2017).

Venture capital investment

Venture capital financing is generally considered as the most suitable external financing mode for new technology based SMEs, such as biotech SMEs (Sohn and Kang 2015). Previous studies highlighted the roles of venture capital investment such as the relaxation of financial constraints, coaching, and networking in leading nations (Bertoni et al., 2010).

Previous studies examined the effects of patents on venture capital investment and the results showed positive relationship between patents and venture capital financing (Kang 2017).

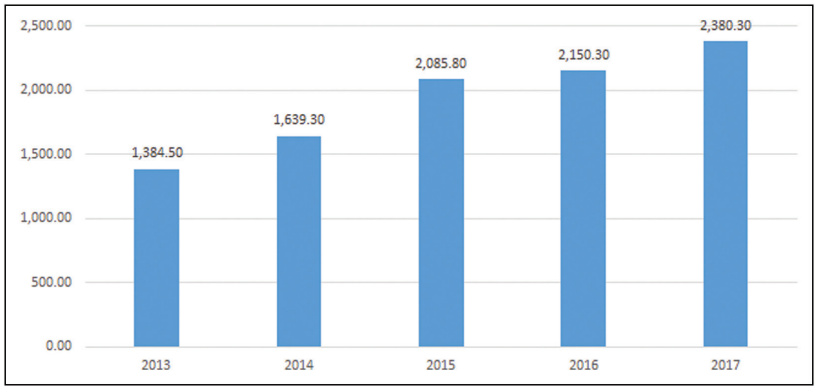
According to empirical studies, venture capital investors perform a key coaching function to the benefit of investee firms (Bertoni et al., 2010). They provide companies, which typically lack internal resources, with advising services in fields such as strategic planning, marketing, finance and budgeting, and human resource management (Bertoni et al., 2010). Furthermore, firms which received venture capital investment can take advantage of the network of social contacts of their VC investors with potential customers, suppliers, and alliance partners (Bertoni et al., 2010). The relaxation of financial constraints, coaching, and networking are all likely to increase R&D productivity (Bertoni et al., 2010). Baum and Silverman (2004) directly address the causality issue between VC investments and firms' patenting activity using 204 biotechnology start-ups located in Canada (Bertoni et al., 2010). Relying on time series regression techniques, they found that the amount of pre-IPO financing is positively affected by patent applications and patents granted in the year before the receipt of VC finance. Sohn and Kang's study showed the mechanism of venture capital investment influencing innovation via promoting downstream collaborations (Sohn and Kang 2015). Amounts of venture capital investment had been growing rapidly with 14.5% CAGR during 2013~2017 and reached 2,380 billion won in 2017 (Figure 3).

The investment in the biotech sector took the largest portion in 2018 3Q (KVCA, 2018) (Figure 4). Venture capital investment would be influencing innovation via coaching function and promoting collaborations.

The credit guarantee system and technology trust

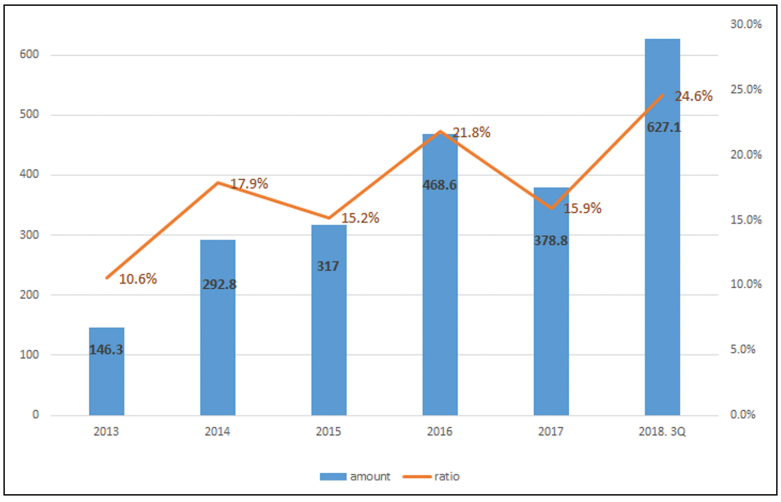
Under the government's drive, Intellectual property holders can monetize their IP more easily in the Republic of Korea (Jung and Kwack 2013). 'The credit guarantee system' has played important role in the SMEs sector. 'The credit guarantee system' has focused on the firm's future potential such as the technology excellence. The system used a quantitative analysis of a firm's business prospects based on the technology that it possesses and provide guarantee services for technology SMEs based on their IP value (Ha 2016, KIBO 2017). It has lessened the SMEs' problem of lack of financial resources (KIBO homepage).

In addition, 'technology trust' has important parts of IP financing (Kang *et al*., 2016). "The term 'technology trust management business' means business engaging in, under a trust agreement with a technology holder on his/her technology and right to use, the management specified by Presidential Decree, such as the settlement or transfer of technology, etc., the collection and distribution of royalties, further development of technology, and technology and asset-backed securitization" (TECHNOLOGY TRANSFER AND COMMERCIALIZATION PROMOTION ACT, Article 2, 8). In Korean, number of organizations which



Source: KVCA 2018

Figure 3: Venture capital investment in Republic of Korea (Unit: billion won)



Source: KVCA 2018, modified by author

Figure 4: VC investment in biotechnology sector (Unit : billion won, %)

obtained technology trust management business via TECHNOLOGY TRANSFER AND COMMERCIALIZATION PROMOTION ACT is only six. More active discussion is needed to revitalize the system.

Conclusion

In Republic of Korea, SMEs participate actively in the biotechnology industry and the biotech SMEs enter into networks with external entities to acquire resources. Previous studies showed that there were significant relationships among networks: Upstream and downstream partnerships were positively associated with innovation performances. In the era of globalization, physical proximity is less important and biotech SMEs needed to be linked with foreign entities. In particular downstream partnerships with foreign entities help firms to generate cash cow or access new markets. Therefore, firms have to try to obtain skill and sensitivity toward resolving the managerial challenges of international collaborations

The Republic of Korean government has considered venture capital investment as one of the important financing instruments and established several public policies encouraging venture capital. As a result, venture capital financing had been growing rapidly with 18.5% CAGR. Venture capital investment would be influencing innovation via coaching function and promoting collaborations.

The credit guarantee system and technology trust have also played important role in the biotechnology industry, which is the most science-intensive sectors. Using intellectual property-based finance, biotechnology SMEs could monetize their Intellectual property more easily and overcome financial difficulties.

References

- ✓ Acs, Z. J. and D. B. Audretsch (1987). "Innovation, Market Structure, and Firm Size", *The Review of Economics and Statistics*, Vol. 69, No. 4, pp.567-574.
- ✓ Audretsch, D. B. (2001). "The Role of Small Firms in U.S. Biotechnology Clusters", *Small Business Economics*, Vol. 17, pp.3–15.
- ✓ Audretsch, D. B. and M. P. Feldman (2003). "Small-Firm Strategic Research Partnerships: The Case of Biotechnology", *Technology Analysis & Strategic Management*, Vol. 15, No. 2, pp.273-288.
- ✓ Baum, J. A. C., Calabrese, T. and B. S. Silverman (2000). "Don't Go It Alone: Alliance Network Composition and Startup's Performance in Canadian Biotechnology", *Strategic Management Journal*, Vol. 21, pp.267-294.
- ✓ Baum, J. A. and B. S. Silverman (2004). "Picking Winners or Building Them? Alliance, Intellectual, and Human Capital as Selection Criteria in Venture Financing and Performance of Biotechnology Startups", *Journal of Business Venturing*, Vol. 19, pp. 411-436.
- ✓ Becheikh, N., Landry, R., and N. Amara (2006). "Lessons from innovation empirical studies in the manufacturing sector: A systematic review of the literature from 1993–2003", *Technovation*, Vol. 26, pp.644–664.
- ✓ Bertoni, F., Colombo, M.G. and A. Croce (2010). "The Effect of Venture Capital Financing on the Sensitivity to Cash Flow of Firm's Investments", *European Financial Management*, Vol.16, No.4, pp.528–551.
- ✓ Burrone, E. (2006). "Patents at the Core: the Biotech Business", WIPO homepage, https://www.wipo.int/sme/en/documents/patents_biotech_fulltext.html
- ✓ Cohen, W. M. and S. Klepper (1992). "The Tradeoff Between Firm Size and Diver-

sity in the Pursuit of Technological Progress", *Small Business Economics*, Vol. 4, No.1, pp.1-14.

- ✓ Galende and de la Fuente (2003). "Internal factors determining a firm's innovative behavior", *Research Policy*, Vol. 32, pp.715-736.
- ✓ George, G. Zahra, S.A. and D.R. Wood (2002). "The effects of business–university alliances on innovative output and financial performance: a study of publicly traded biotechnology companies", *Journal of Business Venturing*, Vol. 17, pp.577–609.
- ✓ Giesecke, S. (2000). "The contrasting roles of government in the development of biotechnology industry in the US and Germany", *Research Policy,* Vol. 29, pp.205-223.
- ✓ Ha J. E. (2016). "Korea's Loan Guarantees for High Tech SMEs", Netherlands Enterprise Agency.
- ✓ Hagedoorn, J. (1993). "Understanding the Rationale of Strategic Technology Partnering: Interorganizational Modes of Cooperation and Sectoral Differences", *Strategic Management Journal,* Vol.14, pp.371-385.
- ✓ Hergert, M. and D. Morris (2002), "Trends in International collaborative agreements". In Contractor FJ and Lorange P (Eds) Cooperative Strategies in international business. Pergamon press: 99-110.
- ✓ Jung, E. J. and J. E. Kwack (2013). "Increasing Monetization of IP assets in Korea", Kim & Chang IP newsletter, Summer/ Fall 2013.
- ✓ Kang, K.-N. (2009). "Factors affecting innovation performance in biotech SMEs: Resource-based view and Value-chain based innovation system approach", Ph.D. dissertation, Seoul National University, Seoul.
- ✓ Kang, K.-N. (2017). Intellectual Property-Based Finance in the Korean SMEs", *International Journal of Management and Applied Science*, Vol. 3, Issue. 2, pp. 52-54.
- ✓ Kang, K.-N., Choi, J.-S. and T.-K. Ryu (2016). "Research on the activation of IP finance using technology trust", Korea Technology Finance Corporation.
- ✓ Kang, K.-N. and H. Park (2012). "Influence of government R&D support and inter-firm collaborations on innovation in Korean biotechnology SMEs", *Technovation*, Vol. 32, No.10, pp.68-78.
- ✓ Kang, K.-N. and Y. S. Lee (2008). "What affects the innovation performance of small and medium-sized enterprises (SMEs) in the biotechnology industry? An empirical study on Korean biotech SMEs", *Biotechnology Letter*, Vol. 30, pp.1699-1704.
- ✓ KIBO (2017). KIBO annual report 2017. Korea Technology Finance Corporation.
- ✓ KIET (2003). "Promoting innovation in the Korean bioindustry: focusing on the technology transfer system", *KIET industry economic review*, Vol. 8, No.2, pp. 29-40.
- ✓ KIET (2004). "The economic impact of biotechnology and bio-industry: methodologies and implications for the bio-industry in Korea", *KIET industry economic review*, Vol.9, No.3, pp. 25-42.
- ✓ KIET (2007). "The economic and non economic impacts of bio-industry in Korea", *KIET industry economic review,* Vol. 12, No. 1, pp.21-38.
- ✓ KBIO (Korea Biotechnology Industry Organization) (2017). "Report on Survey of Domestic Bioindustry based on 2016", Ministry of Trade, Industry and Energy Korea Biotechnology Industry Organization.
- ✓ KVCA (Korea Venture Capital Association) (2018). "Summary Report, 2018. 3Q", Venture Capital Information Center.
- ✓ Mangematin, V., Lemarie´, S., Boissin, J. –P., Catherine, D., Corolleur, F., Coronini, R., and M. Trommetter (2003). "Development of SMEs and heterogeneity of trajectories: the case of biotechnology in France", *Research Policy*, Vol. 32, pp.21–638.
- ✓ OECD (1999). Modern Biotechnology and the OECD, OECD policy brief, http://www.oecd.org/dataoecd/29/40/1890904.pdf
- ✓ OECD (2005). Statistical Definition of Biotechnology. http://www.oecd.org/sti/emerging-tech/biotechnologystatistics-unitedstates.htm
- ✓ OECD (2008). OECD Science, Technology and Industry Scoreboard, OECD publishing
- ✓ Orsenigo L (1989). "The Emergence of Biotechnology: Institutions and Markets in Industrial Innovation", St. Martin's Press, New York.
- ✓ Powell, W. W., Koput, K. W., and L. Smith-Doerr (1996). "Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology", *Administrative Science Quarterly*, Vol. 41, No.1, pp.116-145.
- ✓ Romijn, H. and M. Albaladejo (2002). "Determinants of innovation capability in small electronics and software firms in Southeast England", *Research Policy*, Vol. 31, pp.1053-1067.
- ✓ Rothaermel F. T. and D. L. Deeds (2004). "Exploration and Exploitation Alliances in Biotechnology: A System of New Product Development", *Strategic Management Journal*, Vol. 25, pp.201–221.
- ✓ Rothaermel F. T. and D. L. Deeds (2006). "Alliance type, alliance experience and alliance management capability in high-technology ventures", *Journal of Business Venturing*, Vol. 21, pp. 429– 460.
- ✓ Sasson, A (2004). "Biotechnologies: Current Achievements and Prospects Social Acceptance of Biotechnology-derived Products Medical and Pharmaceutical Biotechnology", Paris, France. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.469.992&rep=rep1&type=pdf
- ✓ Shan, W., Walker, G., and B. Kogut (1994). "Interfirm Cooperation and Startup Innovation in the Biotechnology Industry", *Strategic Management Journal*, Vol. 15, pp. 387-394.
- ✓ Sohn, B.K. and K.-N. Kang (2015). "The Role of Venture Capital on Innovation in the Korean Biotechnology Industry, International Journal of Trade", *Economics and Finance*, Vol. 6, No. 3, pp. 181-185

✓ Stuart, T. E., Ozdemir, S. Z., and W. W. Ding (2007). "Vertical alliance networks: The case of university–biotechnology–pharmaceutical alliance chains", *Research Policy*, Vol. 36, pp. 477–498.

✓ Szuhaj, M. (2008). "How Can Biotechnology Companies Manage Growth and Mitigate Risk in a Global Market?" Area development (Biotech Location Guide, May 08) available from http://www.areadevelopment.com/specialPub/bio08/Biotechnology-Global-Growth.shtml

✓ Zucker, L. G. and M. R. Darby (2001). "Capturing Technological Opportunity Via Japan's Star Scientists: Evidence from Japanese Firms' Biotech Patents and Products", *Journal of technology transfer*, Vol.26, pp.37-58.

✓ Zucker, L. G., Darby, M. R. and M. B. Brewer (1998). "Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises", *The American Economic Review*, Vol. 88, No.1, pp.290-306.

✓ Zucker, L. G., Darby, M. R. and J. S. Armstrong (2002). "Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology", *Management Science*, Vol. 48, No.1, pp.138-153.

Biotechnology Networks and Databases

ASEAN Network on Microbial Utilization
http://www.anmicro.org/

The ASEAN Network on Microbial Utilization serves as a platform for capacity building, resource and knowledge sharing in the area of microbial utilization. It can further catalyze bilateral or multilateral research collaboration among member institutes. This Network creates visibility of ASEAN and attracts collaboration from other regional and international bodies such as the World Data Centre for Microorganisms (WDCM), World Federation for Culture Collections (WFCC) and the Asian Consortium for the Conservation and Sustainable Use of Microbial Resources (ACM).

International Agri-Food Network
https://agrifood.net/

The International Agri-Food Network (IAFN) is an informal coalition of international trade associations involved in the agri-food sector at the global level. The network facilitates liaison among the member organizations and engages international organizations in the agri-food chain at a global level.

ASEAN South American German (ASAG) Biotech Network
http://www.asag-biotech.net/

The ASEAN South American German (ASAG) Biotech Network is a global web portal designed to facilitate and enable the ASAG Biotech Network event alumni and it's associates of scientists, technicians, governmental organisations and policy makers, to easily access information and work groups in the fields of infection research and biotechnology.

GM Approval Database
http://www.isaaa.org/gmapprovaldatabase/

International Service for the Acquisition of Agri-biotech Applications (ISAAA) presents an easy to use database of Biotech/GM crop approvals for various biotechnology stakeholders. It features the Biotech/GM crop events and traits that have been approved for commercialization and planting and/or for import for food and feed use with a short description of the crop and the trait. Entries in the database were sourced principally from Biosafety Clearing House of approving countries and from country regulatory websites. We invite corrections, additions/deletions, and suggestions for the improvement of the database.