1A09 The analysis of technological collaboration based on US Patents

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1. INTRODUCTION

Recently high-technology small and medium companies have been playing an active role in the US economy. Previously the policy concern of small firms was mainly employment, but now their innovative activities as well. They are no longer regarded as laggards unsuitable for advanced technology.
The Small Business Administration's Office of the US published a report that supports the superior innovative activities of small firms,
"Small firms produce twice as many of both product innovations and significant innovations per employees as large firms."

In this paper we try to answer the following question.
Is the capability of SMEs (Small and Medium Enterprises) to innovate increasing (in terms of introducing high-impact inventions)?
If "Yes" what are the enabling factors? If "No" what is the mechanism that increased the role of SMEs in innovation without upgrading of their technological capability?

2. THEORETICAL REVIEWS

EVOLUTIONARY DYNAMICS

The technological factors behind the rise of SMEs are two fold according to the SBA report.
Firstly, new technologies enhanced the relative position of SMEs by changing the economies of scale. Technology such as mini-mill process and flexible manufacturing reduced the minimum efficient scale, which improved the SMEs position. The modular technology encouraged large system integrating firms to spin off the research on components. However, these explanations are mainly about production and not sufficient to understand high-technology SMEs (or New, Technology Based Firms).

Secondly, the rapid technological change which favoured agile SMEs. Here the question can be raised. What is the content of agile response, is it about technology or market? Large firms are not so inferior in monitoring and exploring new technological fields. Large firms have well noticed the direction of current technology with high monitoring capacity [Pavitt 1991]. Christensen argued that the failure of large firms is due to the inherent size that needs large market. Therefore technologically less potent SMEs could outperform large firms through diversity and dynamic mobility with high rate of entry and exit.

TRANSIENT INNOVATION CYCLE

In addition to the above reason, in the early of 1980s, Freeman et al. suggested Schumpeter Mark I and II to explain SMEs different position in innovation cycle. Schumpeter's emphasis on the role of enterprenuer who initiate the radical innovation with novel combination [Schumpeter]. Later, he emphasized that monopolistic rent is essential to invest in research, which is advocating large firms. As symbolized with the phrase "from the Edison Lab into GE", Schumpeter's life was at the center of a period when people experienced growing monopolistic power of large firms. Highly organised research became the dominant pattern of discovery as we could see the number of inventors in a patent increasing. The organised research pattern is largely coined with the maturing chemical and electric innovations.

The postwar innovation waves of microelectronics and IT enhanced the bases of SMEs technological performance. However, whether these innovations' benefits are biased to SMEs is doubtful. They also increased innovations in large firms. In this paper, we try to analyse whether the SMEs (including individual inventors) transformed their profile in terms of technological capability to produce high quality inventions. The issue is linked to the agility of SMEs. If SMEs are agile enough to realize technological opportunity, they are likely to produce major inventions that are improved by further inventions. The role is critical when a new techo-economic paradigm is formed.

UNIVERSITY

The interesting fact is the radical innovation that changed the mechanism of drug discovery came from academic research and Dedicated Biotechnology Firms (DBF). It could be a result of increasing trend of science-intensive technology. Ample evidences show the significant increase in the rapid and direct use of basic research in technology field. [Martin & Irvine]
Universities are instrumental bases that may reduce the entry barrier of firms by providing incubating places and technological opportunities. The 1984 Cooperative Research Act contributed not only to the increase of Intellectual Property Rights of universities but also entrepreneurship. The commercial concern is now deeply affecting the stages before and after university research. It also spurred start-up of high-tech firms by encouraging many higher degree holders to be entrepreneurs.
Whether or not the small firms can grow to be large at last, the continuous entry from universities will keep up persistent technological activities of SMEs.
There are distinctions between science-based and engineering based new enterprises, and science-based

NTBFs (New, Technology Based Firms) emphasising the strong linkage with universities [Autio].

Having reviewed the above literatures above, we found that testing the following hypothesis would be meaningful.

Hypothesis 1: SMEs produce radical inventions with high impact when an innovation cycle starts.
Hypothesis 2: Proliferation of small firms with high quality patenting needs connection with universities' research.

3. METHOD

It is still ambiguous to say whether there is an optimal size of a firm for R&D in terms of efficiency because R&D is not a proper input indicator in most SMEs. Also, innovation statistics use "per employee" instead of "per researcher" can be misleading because large firms have a large labour forces for production, management and distribution. To simplify the comparison, we will try to deal with quality issue. Measuring impact of invention with citation index is a well-established method [Albert at al].

One of the authors developed a autoloading module of Web-based patent DB that is now installed on a Linux system. With the help of the module we could analyse tens of thousands patents even in detail in terms of the citation and co-assignees.
To compare two SMEs and large firms, we chose the US firms that have patents. Large firms are those listed in Fortune Industrial 500 during the period of 1981-1990 at least once. In addition, we downloaded patents of universities, colleges, and institutions in the years 1981-1995. Because the lack of SMEs database, we assigned remained patents to SMEs (thus including individual inventions). For citation, samples of randomly picked 2150 patents for large firms and 665 for SMEs were examined. We selected the period of study because increasing number of high-tech SMEs is reported during the period [Philips].
Although large firms have a higher propensity to apply the patents, we assume that the patents already issued by SMEs have relatively the same opportunity to be cited when compared with those issued by large firms if we restrict our comparison to the patents that received over average citation. This assumption is based on the belief that self-citation of large firms does not cause a significant bias if we choose samples that attained the minimum recognition level.
We assume that the distribution of citation is following a power law, and we made a simple linear model to estimate the constant and the slope.

$$CN = \alpha x^{-\beta}$$

$$\log(CN) = a - b \log x + \varepsilon$$

CN: Cited number,
x: percentage of patents that surpass the CN

The constant means the existence of highly cited patents, and slope means that the distribution of number of citation is relatively flat in the sample.

4. RESULTS AND DISCUSSION

In general, the share of patenting by large firms decreased slightly during the 1980s. The share of university patenting had grown from 0.5% to about 1.5% during the period. Therefore, it means that the reduction of large firms' share is mainly by the expansion of the share of SMEs and individuals. In fact, a legislation to stimulate boost innovation of SMEs - Small Business Innovation Development Act 1982 provided the base of special funding for research in SMEs.

[FIGURE 1]

However, the number of citations received by the large firms' patents remained above that by SMEs'. The SMEs profile improved in terms of citation impact but so did large firms. In both periods (1981-1985 and 1986-1990), the upper bound of SMEs regression line does not cross the lower bound of large firms (95% level of significance).
This result is consistent with the research by Rubenstein and Ettlie that large firms are active in introduction of novel product with new technology.

[TABLE 1]
[FIGURE 2]

The circled area of Figure 2 shows the inclusion of highly cited patents. The actual content of this part are patents of DBFs (Dedicated Biotechnology Firms). The DBFs' high profile is consistent with the findings of French researchers. They identified that the initiating inventions that bring clusters of consequent inventions in biotechnology belong to Dedicated Biotechnology Firms [Joly & de Looze]
To see the role of public (university) research, we made a separate regression on co-applied patents of public institution. The number of university patents increased rapidly during 1980s because of the Cooperative Research Act in 1984. Interestingly the co-applied universities' patents with SMEs are bigger in number than with large firms. Furthermore, the co-applied patents by SMEs and universities have higher impacts than those co-produced by large firms and universities. The result implies high efficiency of collaboration between SMEs and universities. The estimated rates of return on R&D expenditures in firms with a university relationship are 30 percent for large firms and 44 percent for small firms [SBA]. This biased result is witnessed again in citation. The main technological field of co-applied patents are mainly the biotechnology sector, as we find that the top 5 classes that appeared in co-applied patents are medical and biotechnology related. Some frequently appeared classes indicate that the application of lasers is also a popular field of collaborative research.

[TABLE 3]

It is certain that university research is the force behind the phenomena. The start of biotechnology originated from university research, and the start-up DBFs are combinations of enterpreneurs and scientists [Kenney]. Hypothesis 1 on the SMEs role in radical innovation is valid in case of biotechnology innovation. Biotechnology innovation started from 1970s and the first boom of DBFs was at the end of 1970s [opt. ict]. However, in the case of the semiconductor industry, the role of SMEs was different. Radical and basic inventions are from Bell Laboratories in early 50's, and the initial dominance of large firms are complemented with the NTBFs' (New, Technology Based Firms) exploitation of commercial applications [Rothwell and Zegveld]. In the case of microelectronic innovations (semiconductor) universities played a much more indirect role compared to their direct role in biotechnology.

The web based searching system does not support the years prior to 1976, and we could not investigate the citations of NTBFs' patents in the early stage of the microelectronic innovation. Considering the fact noted above, we expect that the NTBFs semiconductor patents are less prominent than the patents by large firms that made the breakthroughs in the field. There is a continuum between the vacuum tube and the transistor in terms of application. The relative continuous evolution from old electronics and telecommunication to microelectronic chips might be a reason, contrasting to the radical advent of biotechnology in drug discovery.

5. CONCLUSION

The US SMEs relative technological competence has not been upgraded significantly when compared with large firms. However, there was a change in some part of SMEs, especially Science-Based NTBFs. Universities made a critical role in the enhancement, which is shown with university-SME co-applied patents

The Schumpeter Mark I model (enterpreneual innovation) is valid in both microelectronic and biotechnology innovations, but the hypothesis on the superior technological competence of SMEs to produce basic invention is only partially true in biotechnology, and not valid in case of microelectronics.

The increased role of SMEs without technically radical inventions mainly depends on evolutionary selection mechanism rather than high-qualities of their technological inventions. The dynamic network of Silicon Valley described by Saxenian shows the characteristics of a nice fit between the effective information flows and high-mobility of labours, which eases the entry-exit process that is critical to selection efficiency. Actually, recent success of SMEs in Information Technology (IT) does not have strong linkage with university research (e.g. Bill Gates did not want the degree). It is rather rapid and proper response to market by using highly efficient IT interface. The recent service sector innovation with IT demands a new indicator to measure radicalness of the innovation.

It is important to identify different the patterns of emergence of SMEs in the semiconductor, biotechnology and software industries.

Although the impact of patent is the main theme of this paper, it is worth noting the NTBFs' diversity in research directions [Almeida and Kogut]. The correlation between diversity and radicalness has not appeared yet, and it is the future subject of this research.

As many scholars identified, sectoral difference in technological opportunities exists and its impact on the size distribution of firms (Pavitt et al, Klevorick at al.). The comparison is highly sensitive to the sector of interest. Within our research width, hypothesis 2 on university linkage as a necessary condition for high impact invention is valid. However, to clarify the role of university to enhance SMEs technological capability, this pilot study should be expanded to longitudinal and sectoral research.

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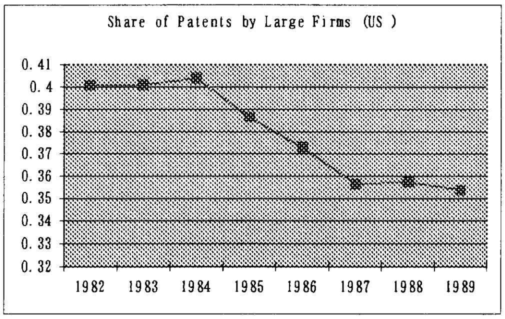

FIGURE 1 Patent share of Fortune 500 (US only)

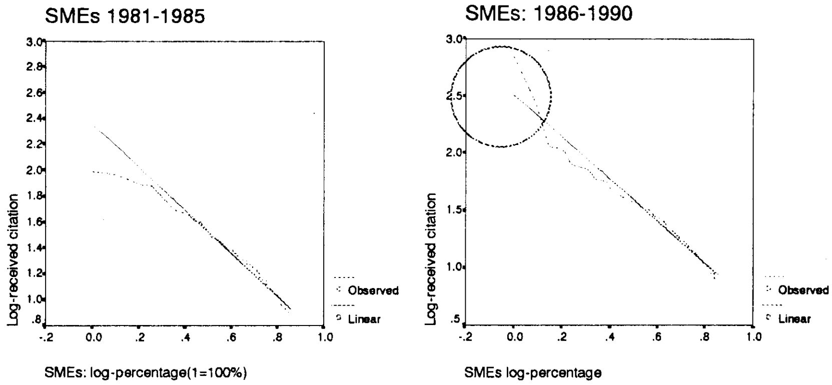

FIGURE 2 Highly cited patents in SMEs

	Large Firms	SMEs
Period1 Constant	2.605	2.353
Slope	-1.879	-1.660
Period2 Constant	2.735	2.508
Slope	-2.021	-1.838

All the results satisfy significant 1% level and Adj $R^2 > 0.96$

TABLE 1 The citation received by large and small firms (cutting off patents with under average citations-received)

	SMEs-Univ&Inst	LargeF-Univ&Inst	Univ&Inst-Univ&Inst
Constant	0.462	0.415	0.432
Slope	-0.397	-0.358	-0.359
Adj R^2	.883	.928	.877

All the regression results satisfy significant 1% level (Regression is on the whole sample)

TABLE 2 Superior quality of SMEs-University co-applied patents during 1981-95.

Rank of Classes	SMEs	Fortune500
1	DRUG, BIO-AFFECTING AND BODY TREATING COMPOSITIONS	
2	CHEMISTRY: MOLECULAR BIOLOGY AND MICROBIOLOGY	
3	DRUG, BIO-AFFECTING AND BODY TREATING COMPOSITIONS	
4	CHEMISTRY: NATURAL RESINS OR DERIVATIVES; PEPTIDES OR PROTEINS;	
5	SURGERY	
6	ORGANIC COMPOUNDS	CHEMISTRY: ANALYTICAL& IMMUNOLOGICAL TESTING
7	RADIANT ENERGY	PLASTIC AND NONMETALLIC ARTICLE SHAPING OR TREATING
8	LIQUID PURIFICATION OR SEPARATION	OPTICS: MEASURING & TESTING
9 -12	-CHEMISTRY OF INORGANIC COMPOUNDS -COATING PROCESSES -CHEMISTRY: ANALYTICAL& IMMUNOLOGICAL TESTING	-COHERENT LIGHT GENERATOR -CHEMICAL APPARATUS AND PROCESS DISINFECTING, DEODORIZING, PRESERVING, OR STERILIZING -STOCK MATERIAL OR MISCELLANEOUS ARTICLES -ORGANIC COMPOUNDS
SHARE	312 (of TOTAL 952)	201 (/ 952)

TABLE 3 The major technological field of cooperation (co-applied patents).