Technological Dynamics: An Empirical Study in Mobile Telecommunications

Hsiao-Chen Mei[1], Shihmin Lo[2], Peter J. Sher[2]
[1]Precision Machinery Research and Development Center, Taichung, Taiwan
[2]National Chi-Nan University, International Business Studies Dept., Puli, Taiwan

***Abstract*—Mobile communication market presents drastically technology changes from the first generation (1G), second generation (2G), third generation (3G) and next fourth generation(4G) in progress. This study investigates the impact of technological change on a firm's development of capabilities in the context of mobile telecommunications. We propose instability of technology scope－the diversity and ranking of patent classes of the industry over time to measure technological changes. In a total of 21 firms and their 286,953 patents related in the field of mobile telecommunications, empirical results show that firms would tend to concentrate technological portfolio in addressing to technological change.**

I. INTRODUCTION

Technological change is regarded as a progress based on specific technological and economic trade-off, which is called "technology paradigm" [8]. In accordance with technological change, dynamic capabilities could be one of theories relatively positing firm's endogenous resources which are influenced by environmental change. Eisenhardt and Martin [9] exhibited two types of markets, namely "moderately dynamic market" and "high velocity market", to explain development of dynamic capabilities. Firms could build dynamic capabilities through evolutionary of detailed and analytic routines or deliberate learning on the existing knowledge in moderately dynamic markets which keeps relatively stable industry structure and the changes could be predictable. In contrast, firms would develop "simple rule" in high velocity markets. It reflects that the pace of technological change would conduct different development of dynamic capabilities.

Technological changes dramatically emerge during recent two decades in mobile telecommunication industry. Analog cellular phone, namely the first generation (1G), evolved into the watershed of digital system, the second generation (2G) in the mid-1980s. With the trend of digital convergence, technologies of the third generation (3G) and the fourth generation (4G) enabling high speed data rate (Mbps) to transmit music, photos and video through mobile device in 2006. Motorola, AT&T, Philips and Bull dominated the technologies related the standard of GSM [13]. Technologies of switching, radio transmission and speech coding were mainly developed. Nokia and Qualcomm emerge in the period of 3G while the standards of WCDMA, CDMA2000, and TD-SCDMA were selected by International Telecommunication Union (ITU). They seriously threat the position of first movers such as Motorola and AT&T [25]. Apparently the firms which ever dominated the market and technologies will be hard to sustain the position in addressing to technological changes. The argument that dynamic capabilities would vary with technological change will associate to the questions: How do dynamic capabilities reconfigure resource base to cope with technological change?

Before we explore the answer, this study adopts one measure called "instability" to evaluate technological change in mobile telecommunication industry. Instability is spearman correlation ρ which combines the diversity and ranking of patent classes of the industry. Higher score of instability indicates technological change to be more fluctuant. On the contrary, lower score indicate it will be more stable. It comprehensively illustrates the fluctuation during technological changes in the fields of mobile telecommunications in response to the cyclical model of technological discontinuities. Tushman and Henderson [34] posit that technology ferment will happen before dominant design emerges, and incremental change will follow the dominant design hereafter. Instability demonstrates relatively unstable before each generation of technological standards set up and hereafter relatively stable in mobile telecommunications industry.

We conduct this study concerning technological change and firm's dynamic capabilities of industry and firm level. We found out firm's activities for developing technology would tend to concentrate technological portfolio while facing drastically technological changes. It implies that firms would deepen technological capabilities to keep technological competitive advantage until industrial standards emerge. Besides, this finding reflects Eisenhardt and Martin's assertion of dynamic capabilities. Firm would address changing condition simply and flexibly with their existing technological capabilities in the high velocity dynamic environment.

The study contributes to the literature by providing theoretical synthesis and evidence with respect to how technology dynamics impact on firms' dynamic capabilities.

This article begins with the theories related to dynamic capabilities and technological changes. Next the hypotheses are developed and following is methodology. The forth we discuss the research results. Finally we make conclusion and suggestion for future research.

II. LITERATURE REVIEW

A.Dynamic Capabilities

Firm is a collection of resources in order profitably to supply goods and service to the market and its growth is an evolutionary process and based on the cumulative growth of collective knowledge (Penrose, 1959). Growth theory initiates the resource-based view (RBV) which is claimed that valuable, rare, inimitable, non-substitutable (VRIN) resources and related sets of operational routines and technological skills are sources of sustained competitive advantage [35][4]. The static and equilibrium-based perspective is not enough to explain how firms cope with the changing environment, especially while firms could not overcome the path dependence and turn core competencies into core rigidities over time [21]. In contrast to RBV, dynamic capabilities emphasize on the dynamics of firm's strategic renewal, adaptation and growth.

The field of dynamic capabilities has developed rapidly over the last decade since Teece, Pisano & Shuen [31] posit that dynamic capabilities as "firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing". Dynamic capabilities lie in organizational processes which are shaped by firm's asset positions and evolutionary paths. Besides of Teece's definition, there is a broad opportunity for scholars to refine the definitions with different lens. Collis [7] terms "meta-capabilities" which "develop the capabilities to develop the capabilities that innovates faster". Eisenhardt and Martine [9] define dynamic capabilities in terms of resource manipulation and their value is defined independently of firm performance. Based with the view of evolutionary economics, dynamic capabilities is defined as higher level capabilities and routines to change routine [38][37]. The definition of dynamic capabilities will be continuously refined more precisely and logically with the effort of scholars. It recently converges on common and precise definition that dynamic capabilities are "the capacity of an organization to purposefully create, extend, or modify its resource base" [17] and are irrelevant to sustained competitive advantage, in contrast to the criticism of tautology [9][17].

Prior literature on dynamic capabilities has placed less emphasis on the underlying process, which is shaped by assets position and molded by the paths [31]. The most of researches on mechanism for change (process) especially link to the issues of organizational learning [22][24][15]. Dynamic capabilities are complicated routines evolving from path dependent processes under the guidance of learning mechanism for shifting the rigidity [31][9][38].

Absorptive capacity [6] and combinative capabilities [20] are regarded as one kind of dynamic capabilities, the former emphasize on the transfer of prior knowledge into new knowledge; the latter point is the capabilities to recombine the external knowledge and internal knowledge.

The processes of acquiring external resources will influence and change organization capabilities. Complementary assets is critical resource for firms to adapt the changing environment under weak appropriability regimes [32] [16][33][1][28][30]. Firms regard alliances as one way to acquire capabilities from alliance partners, and an extensive literature discusses the features of alliances and their participants that facilitate knowledge flow among partners [26] [19].

B. Technological changes and Technological Capabilities

It attracts economists to care about technological change because of its intimate causality link with economic growth. Schumpeter [36] defines technological change as new combination of means of production and proposes the process of technological change as trilogy: invention, innovation and diffusion. With the respective of economic view, a general definition of technological change is that " it constitutes certain kinds of knowledge that make it possible to produce (1) a great volume of output or (2) a qualitatively superior output from a given amount of resources" [29].

Technology is defined "as a set of pieces of knowledge both directly practical and theoretical know-how, method, procedures, experience of successes and failures and also of course physical devices and equipment" [8]. The development of a technology is problem-solving activity with possible technological alternative and imagination of future development.

Technological change is regarded as a progress based on specific technological and economic trade-off, which is called "technology paradigm" [8]. Continuously changes is the progress along with technological trajectories, discontinuities are associated with breakthroughs and emergence of new paradigm.

With the evolutionary perspective, changes in aggregate are the prevalence of various routines held constant from individuals firm. Technological regimes imply the features of environment and identify the dynamic mechanism [36][23]. Winter [36] proposes two different technological regimes with Shumpeter's two views of innovation, entrepreneur and established large firms, in correspondence with the entrepreneurial regime and routinized regime to explain exogenous factors including the environmental conditions as appropriation, technological opportunity, cumulative knowledge and imitation.

Tushman and Anderson [34][2] propose a cyclical model of technological change which is an evolutionary model of technological discontinuities, as the product or process breakthroughs, which initiates an era of ferment, dominant design and incremental change. Technological discontinuities will be will be punctuated either by competence-enhancing or competence-destroying discontinuities. "Competence-enhancing discontinuities" build on existing skills and know how, in contrast, "competence-destroying discontinuities" require fundamental new skill and competence"[34]. In accordance to the cyclical technological change of ferment, dominant design and incremental change, dominant design will be a crucial period for firms building the capabilities. A dominant design ends the period of technological ferment and the beginning of a period of incremental change and opens the window of learning for incumbents and new entrants whose innovations conform to the dominant design [5]. This echoes the Zollo and Winter's assertion that "dynamic capabilities arise from learning" [38], wherein the period of dominant design the industry is abundant with information for firms to learn and to build the capabilities.

Technological capabilities define the roots of a firm's sustainable competitive advantage in the concept of resource-based view. Technology dominates product or production process, the former includes those tools, devices, and knowledge that mediate between inputs and output, the latter includes those that create new products or services. The types of technological change emerge as incremental innovation, architectural innovation, modular innovation and radical innovation according to the magnitude of change between core concepts or its linkage to components [18].

Under the appropriability regimes, whereas the capabilities comprise patents protected by legitimacy, technological knowledge and production skills that are valuable and difficult to imitate by competitors. During the emergence of dominant designs exhibits that there could be some significant information sources for sharing and learning, for example public information of patents and standards, and would affect the dynamic capabilities, which present as the portfolio of technology.

Direction of technology development could be categorized into technological concentration or diversification. Technological diversification means that firms build new capabilities to diverse product applications [3]. Technological concentration indicates deepening existing technological capabilities. Firm’s technological capabilities usually are constrained by what to be searched with path dependency [27].

III. HYPOTHESIS DEVELOPMENT

Technologies are regarded as one of firm’s strategic resources. Firms could built technological capabilities internally or externally through the way of research and development, alliance collaboration and technology transfer from the technology market.

Concentration on core technologies will enhance the economics of scale through learning process and benefit from technological comparative advantages. Because technological competence should be specific, unique and complex, firms are inclined to accumulate technological knowledge through research and development or collaboration under condition of tight appropriability regimes [32].

Technological changes imply uncertainty and volatility. In moderately dynamic environment, wherein changes could be predictable, firms could deliberately learning and adapt capabilities to new condition underlying existing knowledge [9][38]. But in the high velocity dynamic environment, firms would cope with changing condition simply and flexibly by their existing technological capabilities. More rapidly the technologies change, more increasingly concentration of the technological portfolio would be enforced. Therefore, firms could not diversify the technological scope if external technological changes are unpredictable.

Hypothesis: Technological changes would positively influence technological concentration.

The conceptual framework is shown as FIGURE 1.

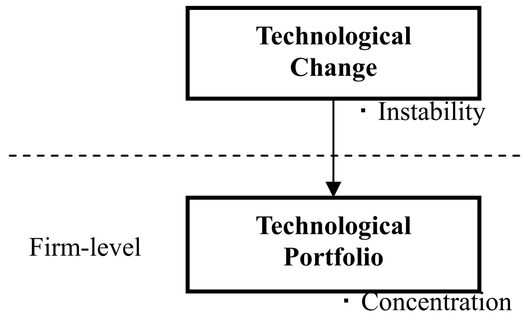

FIGURE 1. Conceptual Framework

IV. METHODS

A. Empirical Context: Mobile Telecommunications

The blueprints of future digital GSM standards were laid out with the effort Conference on European Post and Telecommunications (CEPT)[1] in mid 1980s. An analysis of essential patents in the technological fields of GSM shows the technologies was dominated by Motorola, AT&T, Philips and Bull. The early patents are based on the fields of switching, radio transmission and speech coding [13]. In early period of GSM, GSM group contemplated two version of same basic technology: Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA). FDMA was mainly deployed as the basis for digital mobile telecommunications in America. European adopted TDMA as the basis technology. Herein, a lot of European firms decided to develop wideband-TDMA (WCDMA) for application requirement of more bandwidth in the air. Personal Digital Cellular (PDC) was adopted as the technology of digital mobile telecommunication in Japan.

International Telecommunication Union (ITU)[2] created International Mobile Communication 2000 (IMT 2000) structure of 3G and the final selection of IMT-2000 radio transmission technologies is made in 2000. There are three main standards of mobile telecommunications passing selection by ITU, WCDMA, CDMA2000, and TD-SCDMA. Nokia and Qualcomm emerge in the period of 3G, and seriously threat the position of first movers such as Motorola, AT&T and etc. The number of subscribers on mobile phone rouses to 5, 102 million globally (see FIGURE 2) and grows rapidly.

[1] Conference on European Post and Telecommunications (CEPP) which is responsible for the creating European standards for mobile telecommunication initially. CEPT lost its initiative and leadership of European telecommunication scene after establishment of ETSI.

[2] International Telecommunication Union (ITU), which was founded in 1865, is the United Nations agency for information and communication technology issues, and the global focal point for governments and the private sector in developing networks and services.

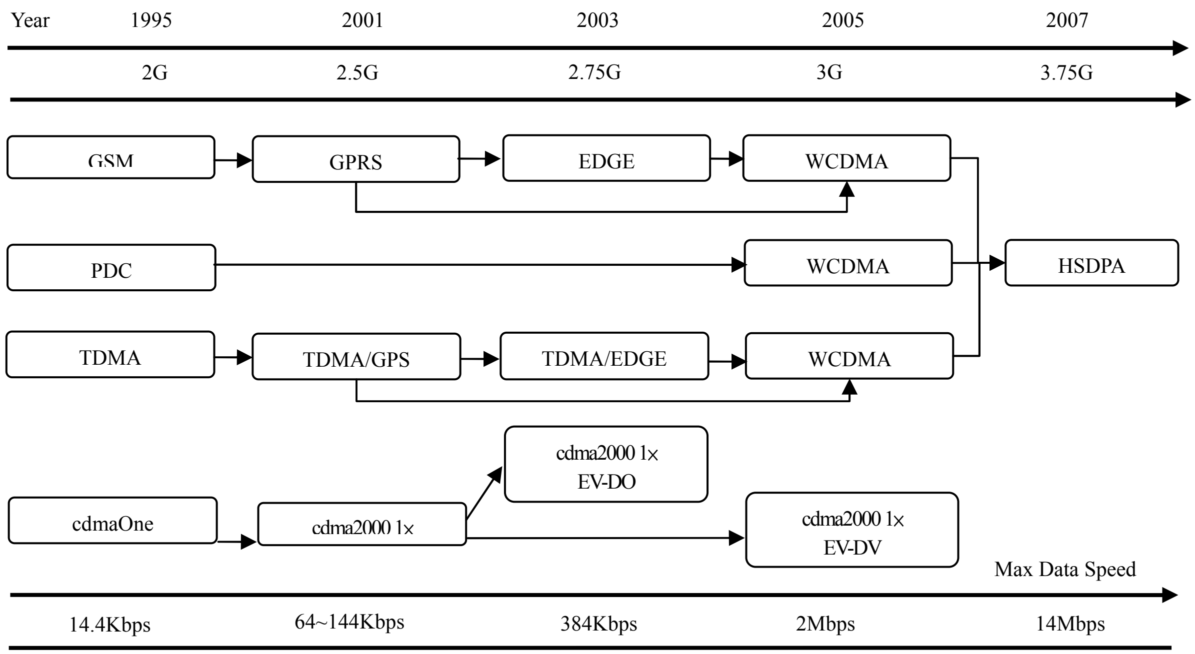

FIGURE 2 Standard Evolutions from 2G to 4G

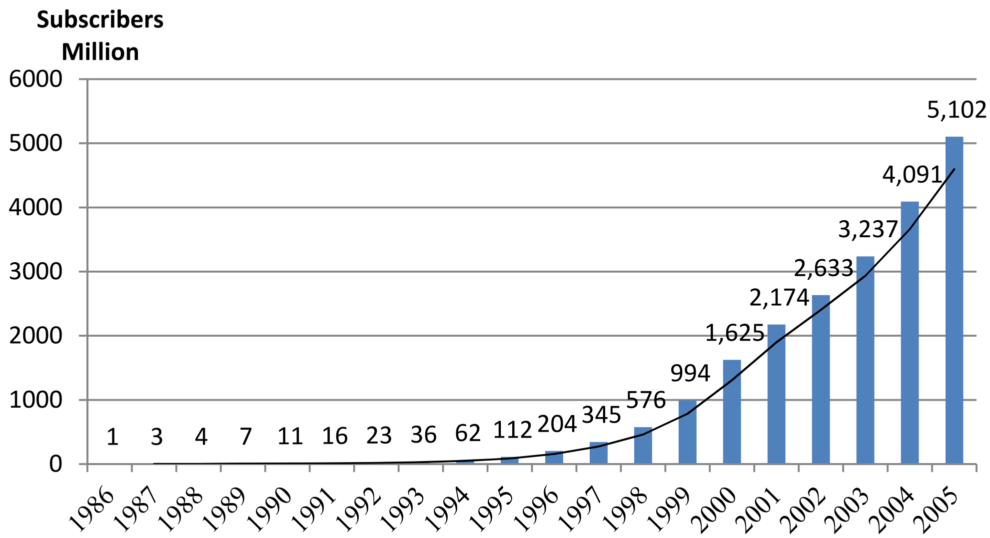

FIGURE 3 Mobile Cellular Telephone Subscribers - (Post-paid + Pre-paid)

The product categories in the field of mobile telecommunications cover widely and might overlap with internet. Main product categories relate to transmission might be radio access equipment, terminal devices, protocol, software, application and service (see Appendix). The infrastructures of mobile telecommunications form an entirely complex ecology of technologies with standards, alternative subsystems and components. Convergence definitely is the future trend for consumer market, and it includes not only mobile telephony, but also personal digital assistant, music and video, multimedia, game, GPS, MMS and etc.

B. Methods and Data

Dependent variable is technological concentration and independent variable is technological change (see TABLE 1).

TABLE 1 DESCRIPTION OF VARIABLES

Variables	Description
Dependent variables	
dTD	TD_i means technological concentration of firm *i*, the indicator is $TDi=\Sigma S_{ij}PS_{ij}$. whereas $PS_{ij}=X_{ij}/\Sigma X$ and S_{ij} represents patent share of each technology j within the firm i .PS_{ij} represents patent share of firm i on technology j within all the patents on technology class j. dTD is an increasing value as TD_t compared to TD_{t+1}.
Independent variables	
TCinstabilty	Technological changes, the indicator is spearman correlation ρ of scope and scale by year: $\rho = 1 - \frac{6\sum d_i^2}{n^3 - n}$

Based on the research framework, three models are used respectively with the panel data specification:

$$\mathbf{Y_{it}=bX_{it}+(a+u_i)+e_{it}}$$

With the panel data we can explicitly allow for firm heterogeneity and avoid omitted variable bias in the regression. Firstly, F test is used to verify if there is firm heterogeneity and the fixed effect (FE) model is more appropriate than the pooling (OLS) model. Secondly, Hausman test is used to verify whether the firm heterogeneity is better specified by fixed effect (FE) model when the null hypothesis of E(uiXit)=0 is rejected or by random effect (RE) model which ui is assumed uncorrelated with the other regressors in the random-effect model. The non-spherical disturbance such as heteroskedasticity (HSK) could be resolved in estimated generalized least square (GLS) process in RE model. Therefore, the empirical models are specified as below.

$$dTD_{it}=Const+b1*\ TCinstabilityit_{it}+u_i+e_{it}$$

C. Data Collection and Sample

The data resources come from public database including European Telecommunications standards Institute (ETSI) IPR database [10][11][12], United States Patent and Trademark Office (USPTO) patent database. Twenty-one companies which declared the patents aggressively in ETSI were selected as target sample. Their essential patents totally dominate 74.9% total amount (see TABLE 2).

TABLE 2. SAMPLE PROFILE OF FOCAL FIRMS

Company	Claimed essential patents	%	Patents in the fields of telecommunications	%
QUALCOMM	656	23.6%	4,065	1.4%
NOKIA	438	15.8%	7,648	2.7%
ERICSSON	281	10.1%	9,891	3.4%
LG ELECTRONICS	178	6.4%	7,435	2.6%
MOTOROLA	141	5.1%	22,713	7.9%
NORTEL NETWORKS	44	1.6%	5,935	2.1%
PHILIPS ELECTRONICS	44	1.6%	16,300	5.7%
NEC	39	1.4%	26,716	9.3%
TEXAS INSTRUMENTS	34	1.2%	18,658	6.5%
ALCATEL/ LUCENT	38	1.4%	22,055	7.7%
MATSUSHITA ELECTRIC	32	1.2%	32,853	11.4%
SAMSUNG ELECTRONICS	32	1.2%	30,172	10.5%
HUGHESEL ECTRONICS	28	1.0%	3,279	1.1%
ASUSTEK	18	0.6%	309	0.1%
RESEARCHIN MOTION	17	0.6%	946	0.3%
TOSHIBA	15	0.5%	27,011	9.4%
APPLE	11	0.4%	3,624	1.3%
SIEMENS	10	0.4%	25,514	8.9%
AT&T	8	0.3%	11,888	4.1%
BRITISH TELECOMM	7	0.3%	1,323	0.5%
BROADCOM	6	0.2%	8,618	3.0%
Subtotal	2,077	74.9%	-	0.0%
Others	697	25.1%	-	0.0%
Total	2,774	100%	286,953	100.0%

We select not only 2,774 essential patents but also all focal firm's patents related to mobile telecommunications during 1986 to 2005, which is the transition period of technological evolution from 2G to 3G. As compared to the standard evolution of mobile telecommunications, we suggest that it would approximately take ten years to implement the technologies in each generation. There are 286,953 US patents in this study. Because boundary of each firm is various, patents are screened by the technologies in the fields of telecommunications.

The essential patents distribute 20 IPC classes dominating 97.3% of total amount (see TABLE 3). The number of patents in the fields of multiplex communication (H04J) and transmission of digital information (H04L) apparently increases after 1996. We use the eighth edition of the IPC (IPC-2006), which entered into force on January 1, 2006. Codes are defined as the appendix.

TABLE 3 ETSI ESSENTIAL PATENTS (US) BY IPC

IPC	1895-1985		1986-1995		1996-2005		2006-2010		Total	
	Count	%	Count	%	Count	%	Count	%	Count	%
G01R	0	0.0%	0	0.0%	6	0.4%	0	0.0%	6	0.2%
G01S	0	0.0%	21	4.6%	66	4.1%	7	1.0%	94	3.4%
G06F	0	0.0%	14	3.1%	64	4.0%	28	4.1%	106	3.8%
G06K	0	0.0%	4	0.9%	7	0.4%	0	0.0%	11	0.4%
G06Q	0	0.0%	0	0.0%	6	0.4%	0	0.0%	6	0.2%
G06T	0	0.0%	8	1.8%	2	0.1%	0	0.0%	10	0.4%
G08C	0	0.0%	0	0.0%	6	0.4%	5	0.7%	11	0.4%
G10L	5	21.7%	47	10.3%	78	4.8%	2	0.3%	132	4.8%
H01Q	0	0.0%	7	1.5%	3	0.2%	1	0.1%	11	0.4%
H03G	0	0.0%	5	1.1%	3	0.2%	0	0.0%	8	0.3%
H03M	0	0.0%	9	2.0%	45	2.8%	8	1.2%	62	2.2%
H04B	5	21.7%	144	31.5%	445	27.5%	139	20.5%	733	26.4%
H04H	0	0.0%	1	0.2%	8	0.5%	3	0.4%	12	0.4%
H04J	2	8.7%	38	8.3%	224	13.9%	74	10.9%	338	12.2%
H04K	0	0.0%	1	0.2%	2	0.1%	9	1.3%	12	0.4%
H04L	1	4.3%	41	9.0%	341	21.1%	125	18.4%	508	18.3%
H04M	3	13.0%	24	5.3%	49	3.0%	19	2.8%	95	3.4%
H04N	0	0.0%	2	0.4%	15	0.9%	3	0.4%	20	0.7%
H04Q	0	0.0%	6	1.3%	40	2.5%	29	4.3%	75	2.7%
H04W	4	17.4%	55	12.0%	172	10.6%	217	32.0%	448	16.1%
Missing	3	13.0%	30	6.6%	34	2.1%	9	1.3%	76	2.7%
Total	23	100%	457	100%	1,616	100%	678	100%	2,774	100%

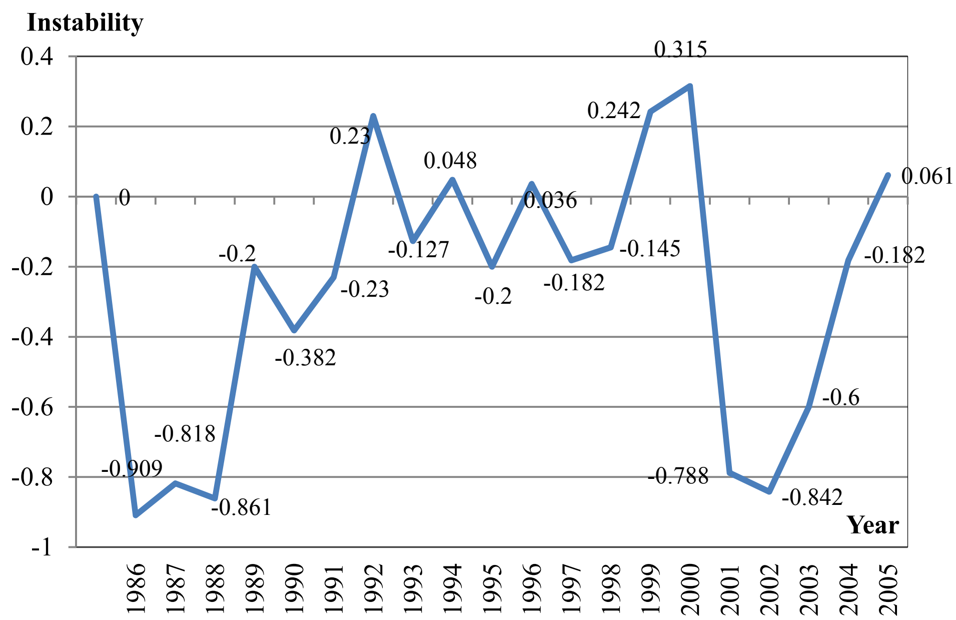

FIGURE 4 Technological changes in mobile telecommunications industry

D. Statistical Analysis

IPC classes of patents indicate the technological evolution of 3G. We use IPC classes each year to calculate the technological instability which is spearman correlation ρ. Higher score of instability represents technological change more fluctuant and lower score on the reverse. FIGURE 4 generally illustrates technological changes in mobile telecommunications industry before 2005. In comparison with standards selection of 2G and 3G, it is relatively stable during the time of digital GSM (2G) standards laid out in 1986/1987. It's fluctuating during 1991 to 2000. Final selection of IMT-2000 (3G) was made in 2001, hereafter the instability declines again. It could be predictive to fluctuate repeatedly before next generation emergence, 4G for example. Instability describes comprehensively technological changes in the fields of mobile telecommunications in accordance to the cyclical model of technological discontinuities proposed by Tushman and Henderson [34][2].

This empirical study aims to investigate antecedents, the dynamic capabilities, which influence firm's technological portfolio under the condition of technology dynamics. Descriptive statistics and correlation of the variables are shown in TABLE 4 and TABLE 5.

TABLE 4 DESCRIPTIVE STATISTICS OF THE VARIABLES

Variables	Number of Observations	Mean	Std. Dev.	Min	Max
dTD	420	0.00	0.02	-0.06	0.23
TCinstability	420	0.28	00.39	-0.32	0.91

TABLE 5 CORRELATIONS BETWEEN VARIABLES

	dTD	TCinstability
dTD	1.00	
TCtcstability	0.01	1.00

Note : +p<0.1, *p<0.05; **p<0.01, *** p<0.001

TABLE 6 ESTIMATE FOR TECHNOLOGICAL CONCENTRATION

dTD	FE	RE
TCtcinstability	0.015*** (0.005)	0.016*** (0.004)
_cons	-0.002 (0.003)	0.001 (0.002)
F-value	2.86***	
Wald chi^2		23.460**
R-sq		
Within-firm	0.081	0.076
Between-firm	0.363	0.429
Overall	0.080	0.087
No. of observation	253	253
F test	0.93	
Hausman test	3.26	

Note :1. +p<0.1,*p<0.05; **p<0.01, *** p<0.001
[2] Standard errors are in parentheses.

The result of panel data analysis indicates that instability of technological changes in mobile telecommunications industry would positively affect technological concentration. Hypothesis 2 is supported. (see TABLE 6)

E. Results and Discussion

We propose instability as one measurement to describe technological changes. Instability is reflected by diversity of technology scope. It is relatively stable during the time of digital GSM (2G) and IMT-2000 (3G) standards have be laid up and is fluctuating during the transition from 2G to 3G (see FIGURE 5). This result is actually in accordance to the cyclical model of technological discontinuities proposed by Tushman and Henderson [[34][2]. The model indicates that breakthrough would initiate an era of ferment, dominant design and incremental change.

The findings also point out firm's activities for developing technology would tend to concentrate technological portfolio while facing drastically technological changes. It implies that firms would deepen technological capabilities to keep technological competitive advantage until industrial standards emerge. Besides, this finding reflects Eisenhardt and Martin's assertion of dynamic capabilities. Firm would address changing condition simply and flexibly with their existing technological capabilities in the high velocity dynamic environment.

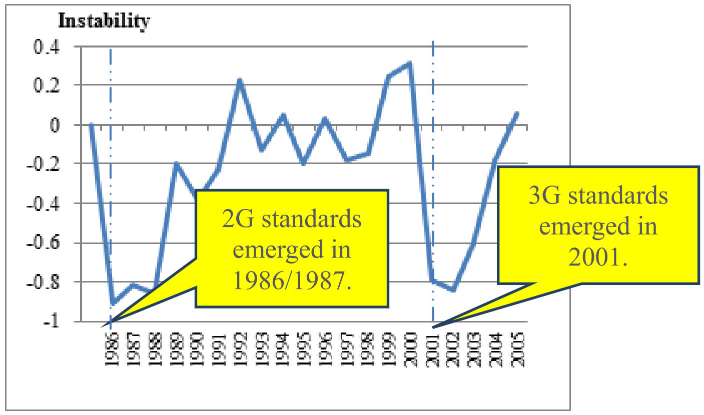

FIGURE 5 Instabilities and standards emergence

VII. CONCLUSION

The study empirically illustrates technological change in mobile telecommunication industry over recent two decades and investigates how firms build technological capabilities to address dynamic changing technologies. We conduct this study concerning technological changes and dynamic capabilities with the view of both levels of industry and firm level simultaneously. We use instability, which is a compound index of the diversity and amount of technology classes, to measure technological changes for recent two decades in mobile telecommunications industry. As a result, the fluctuation of instability fits the evolutionary model of technological discontinuities.

Furthermore, we empirically examine dynamic capabilities which is defined as firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing" [31] and the capacity of an organization to purposefully create, extend, or modify its resource base" [17][37][38]. The study investigates how dynamic capabilities modify firm's technological portfolio while facing technological changes. In a total of 21 global firms and 286,953 patents related in the field of mobile telecommunication, we prove firms would concentrate firm's technological portfolio in addressing to technological changes.

A. Limitation and Future Research

This study adopted two data sources of ETSI and USPTO. Essential patents are self-declared by firms in ETSI without third party certification. Goodman and Myer (2005) suggested that approximately 21% of the declared patents are actually essential through professional valuation [14]. And it is possible the truly essential patents are not declared. Ownership of patents would not be disclosed completely in USPTO, since patent right could be transferred under agreement. There exists inconsistency on ownership and assignee between the data bases of ETSI and USPTO.

Firstly, we suggest there should be research linking network externalities and dynamic capabilities in mobile telecommunications industry. Dynamic capabilities might be contingent to different company especially characterized with technologies dominant, compatible or complementary. Secondly, we suggest further research on firm's managerial process and performance. Thirdly, since mobile telecommunications systems are a paradigm with large technical system requiring technical interface standardization. The competitive dynamics on the battle of standards deserves to have in-depth research on how these interaction influences capabilities building. Finally, merger and acquisition are strategic activity to acquire technologies and are worthy to have research as one of dynamic capabilities.

B. Contribution

The issues of identifying dynamic capabilities still have opportunities for empirical research. The study contributes to the literature by providing theoretical synthesis and evidence with respect to how technology dynamics impact on firms' dynamic capabilities.

REFERENCES

[1] Afuah A. "How much do your co-opetitors' capabilities matter in the face of technological change?", *Strategic Management Journal*, 21: 387-404, 2000.

[2] Anderson P., Tushman M.L., "Technological discontinuities and dominant designs: A cyclical model of technological change", *Administrative Science Quarterly*, 35(4): 604-633, 1990.

[3] Argyres N., "Capabilities, technological diversification and divsionalization", *Strategic Management Journal*, 17:395-410, 1996.

[4] Barney J., "Firm resources and sustained competitive advantage", Journal of Management, 17: 99-120, 1991.

[5] Christensen C., Suarez F., Utterback J., "Strategies for survival in fast-changing industries", *Management Science*, 44(12): 207-220, 1998.

[6] Cohen M., Levinthal M., "Absorptive capacity: a new perspective on learning and innovation", *Administrative Science Quarterly*, 35: 128-152, 1990.

[7] Collis D.J., "How valuable are organizational capabilities?", *Strategic Management Journal*, 15:143-152, 1994.

[8] Dosi G., "Technological paradigms and technological trajectories", *Research Policy*, 11. 147-162, 1982.

[9] Eisenhardt K.M., Martin J., "Dynamic capabilities: what are they?", *Strategic Management Journal*, 21:1105-1121, 2000.

[10] ETSI introduction "European Telecommunications standards Institute", Retrieved 10/15/2009 ETSI website, http://www.etsi.org/Website/aboutETSI/aboutETSI.aspx

[11] ETSI IPR database, Retrieved 12/17/2009 ETSI website, http://www.etsi.org/IPR/home.asp (accessed on Dec.17, 2009)

[12] ETSI IPR policy, "Annex 6 of the Rules of Procedure", Retrieved 10/15/2009 ETSI website, http://www.etsi.org/WebSite/document/Legal/ETSI_IPR-Policy.pdf

[13] Glimstedt H., "Competitive dynamics of technological standardization: the case of third generation cellular communications", *Industry and Innovation*, 8: 49-78, 2001.

[14] Goodman D., Myers R., "3G cellular standards and patents", *IEEE WirelessCom 2005.*

[15] Grant R.M., "Prospering in Dynamically-competitive environment: Organizational capability as knowledge integration", *Oraganization Science*. 7(4): 375-387, 1996.

[16] Helfat C.E., "Know-how and asset complementarity and dynamic capability accumulation: The case of R&D", *Strategic Management Journal,* 18(5): 339-360, 1997.

[17] Helfat C.E., Finkelstein s., Mitchell W., Peteraf M.A., Teece D.J., Winter S., "Dynamic capabilities: Understanding strategic change in organizations", UK : Blackwell Publishing, 2007.

[18] Henderson R., Clark K.B., "Architectural Innovation: The reconfiguration of existing product technologies and the failure of established firms", *Administrative Science Quarterly*, 35:9-30, 1990.

[19] Kale P., Singh H., "Building firm capabilities through learning: the role of the alliance learning process in alliance capability and firm-level alliance success", *Strategic Management Journal*, 28(10): 981-1000, 2007.

[20] Kogut B., Zander., "Knowledge of the firm, combinative capabilities, and replication of technology", *Organization Science*, 3(5):383-397, 1992.

[21] Leonard-Barton D, "Core capabilities and core rigidities: A paradox in managing new product development", *Strategic Management Journal*, 13:111-125, 1992.

[22] Levit B., March J.G., "Organizational learning", *Annual Review of Sociology*, 14: P319-340, 1988.

[23] Malerba M., Orsenigo L., "Technological regimes and firm behavior", *Industrial and corporate change*, 2: 45 – 71, 1993.

[24] March J.G., "Exploration and exploitation in organizational learning", *Organization Science*, 2(1): 71-87, 1991.

[25] Mei H.C., Che J.L., Lo S.M., Sher P.J., "Does Technological Standardization Enhance or Inhibit Firm's Capabilities? Research on Dynamic Capabilities in the Mobile Communication Market", Proceedings of PICMET Conference, Phuket , July 2010.

[26] Mowery D.C., Oxley J.E., Silverman B.S., "Strategic alliances and interfirm knowledge transfer", *Strategic Management Journal*, 17: 77-91, 1996.

[27] Patel P., Pavitt K., "The technological competencies of the world's largest firms: complex and path-dependent, but not much variety", *Research Policy*, 26: 141-156, 1997.

[28] Rothaermel F.T., "Technological discontinuities and complementary Assets: A longitudinal study of industry and firm performance", *Organization Science,* 16(1): 52-70, 2005.

[29] Rosenberg N., "Inside the black box: technology and economics", Cambridge University Press, 1982.

[30] Stieglitz N., Heine K., "Innovations and the role of complementaries in a strategic theory of the firm", *Strategic Management Journal,* 28(1): 1-15, 2007.

[31] Teece D.J., Pisano G., Shuen A., "Dynamic capabilities and strategic management", Strategic Management Journal, 18(7): 509-533, 1997.

[32] Teece D.J., "Profiting from technological innovation: implications for integration, collaboration, licensing and public policy", *Research Policy*, 15: 285-305, 1986.

[33] Tripsas M., "Unraveling the process of creative destruction: complementary assets and incumbent survival in the typesetter industry", *Strategic Management Journal*, 18:119-142, 1997.

[34] Tushman M.L., Anderson P., "Technological discontinuities and organizational environments", *Administrative Science Quarterly*, 31(3): 439-465, 1986.

[35] Wernerfelt B., "A resource-based view of the firm", *Strategic Management Journal,* 5:171-180, 1984.

[36] Winter S., "Schumpeterian competition in alternative technological regimes", *Journal of Economic Behavior Organization*, 287-320, 1984.

[37] Winter S., "Understanding dynamic capabilities", *Strategic Management Journal,* 24: 991-995, 2003.

[38] Zollo M., Winter S., "Deliberate learning and the evolution of dynamic capabilities", *Organization Science*, 12(3): 339-351, 2002.

APPENDIX

Description of top 20 IPC classes

IPC Class	Description
G01R	Measuring electric variables; measuring magnetic variables
G01S	Radio direction-finding; radio navigation; determining distance or velocity by use of radio waves; locating or presence-detecting by use of the reflection or reradiation of radio waves; analogous arrangements using other waves of electric digital data processing.
G06F	Electric digital data processing.
G06K	Recognition of data; presentation of data; record carriers; handling record carriers.
G06Q	Data processing systems or methods, specially adapted for administrative, commercial, financial, managerial, supervisory or forecasting purposes.
G06T	Image data processing or generation
G08C	Transmission systems for measured values, control or similar signals.
G10L	Speech analysis or synthesis; speech recognition; audio analysis or processing.
H01Q	Aerials
H03G	Control of amplification.
H03M	Coding, decoding or code conversion, in general.
H04B	Generation of oscillations, directly or by frequency-changing, by circuits employing active elements which operate in a non-switching manner; generation of noise by such circuits.
H04H	Impedance networks, e.g. resonant circuits; resonators
H04J	Multiplex communication
H04K	Electric communication technique
H04L	Transmission of digital information, e.g. telegraphic communication
H04M	Telephonic communication
H04N	Pictorial communication, e.g television
H04Q	Selecting
H04W	Wireless communication networks