University of Oxford

Department of International Development

ISSN 2045-5119

TMD Working Paper Series

No. 037

Differential Forms of Technological Evolution and Catch-Up: Evidence from China

Fangrui WANG, Xiaolan, FU, and Jin CHEN

Differential Forms of Technological Evolution and Catch-Up: Evidence from China

Fangrui WANG[1,2], Xiaolan, FU[2], and Jin CHEN[1]

[1] Zhejiang University, Hangzhou 310027, China

[2] University of Oxford, Oxford, OX1 3TB, UK

Abstract:

Based on a categorization of technological change, this paper proposes three patterns of catch-up: incremental, disruptive, and revolutionary. Variations in innovation forms within the three patterns of catch-up are analyzed using Chinese firm-level survey data. The evolution of innovation follows an inverted U-shape in the case of the incremental pattern of catch-up. The disruptive form of catch-up follows a linear curve rather than the N-shape proposed by theory. In the case of the revolutionary pattern of catch-up, the evolution of innovation also follows an inverted U-shape but one which is less flat than that involved in the incremental pattern.

Keywords: Technological Evolution, Catch-Up, China

Corresponding author *: Fangrui WANG, Tel/Fax: 86 571 87953882, E-Mail: fangrui.wang@yahoo.com,*

Postal Address: Room 518, Building 11, Zheda Road 38, Zhejiang University, Hangzhou 310027, China

1. Introduction

China's economic growth since its liberalizing reforms has been impressive. Despite this achievement, survey and statistical evidence suggest that there are serious problems in its strategy of technology development. According to a survey report on indigenous industrial innovation capabilities by the Chinese Administration of Science and Technology in 2006, most industries become trapped into augmenting existing manufacturing capacity via the importing of equipment and technology whilst investing less and less into research activities and emerging technologies. Other statistical evidence on national manufacturing innovation from 2004 to 2006 issued by China's National Bureau of Statistics shows the same result in terms of technology strategy. Most of the surveyed manufacturing firms sit within the comfort of continuous improvements to existing technologies. Only 9% aim at catching up with the leading domestic competitor and only 2.7% aim at catching up quickly with leading international competitors.

The field of latecomer studies gives significant emphasis to the strategic problem of technological development, paying attention to the dynamics of the evolution from imitation to innovation along specified trajectories or patterns of catch-up. Some researchers have argued in support of an incremental path from the importing of technology to the creation of original R&D (e.g. Kim, 1997; Hobday, 1995). Other researchers have proposed a leapfrog method, either by utilizing a window for technological development or by creating a new path (e.g. Perez and Soete, 1988; Lee and Lim, 2001). In order to analyze the possible forms of technological development, the above research has usually been based upon two mechanisms derived from a theory of technological change. These two mechanisms created a foundation for the study of the evolution of innovation. First, the process of the evolution of innovation or rather technology development is path dependent (Hobday, 1995) constrained by the technology paradigm (Dosi, 1982) and the technology regime (Nelson and Winter, 1982). The path dependence of technological development suggests a continuous process in the evolution of innovation involving incremental improvements. Second, the anticipation of technological change plays a key role in adjusting the strategic orientation of technology development (Kim, 1999; Li and Kong, 2006). This indicates that turning points occur usually with radical innovation.

Although the existing literature has provided us with clues to the possible forms of technological development, this paper suggests that there at least two questions regarding the evolution of innovation which have not yet to be answered satisfactorily. First, it still remains open as to how to tackle the dilemma of imitation versus innovation and the question of when to move from imitation to innovation during a given process of technological development (Hobday, 1995; Hobday et al., 2004). Second, a simple differentiation between imitation on the one hand and innovation on the other does not adequately reflect the complexity involved in making an appropriate categorization. For example, Chakrabarti (1989) proposed four types of innovation: radical innovation, major technological change, improvement of existing technology, and imitation of existing technology. Use of a more detailed categorization of innovation is fundamental to any proper quantitative study of the evolution of innovation..

In this paper, we intend to approach these questions relating to the evolution of innovation by developing dynamic models for all possible patterns of catch-up and by testing them against survey data relating to Chinese firms. First, technological change is re-categorized in order to provide a general framework for the analysis of trajectories of technology development. Second, patterns of catch-up are investigated with a view towards developing a new categorization of technological change. Finally, each dynamic model of the evolution of innovation is developed in relation to a specified pattern of catch-up. On the basis of these dynamic models, we develop separate hypotheses regarding the evolution of innovation and the point at which transition occurs. We speculate that the evolution of innovation demonstrates variations in the level of novelty and thus the decision of firms to invest in innovation is not simply a matter of deciding whether to imitate mature technologies or develop new technologies, as is suggested by many researchers (e.g. Nelson and Winter, 1982). We believe that this paper will contribute to the literature by developing a new categorization of technological change and patterns of catch-up. This new categorization may lay a good foundation for further empirical studies to reach comparative conclusions about the evolution of innovation. Furthermore, the testing of dynamic models of the evolution of innovation will provide a better framework for technological development strategies which resolve the dilemma between imitation and innovation and help answer when to move from imitation to innovation.

The remainder of this paper is organized as follows. Following this introduction, Section 2 reviews the literature and provides our theoretical expectations. Section 3 introduces the research methods, including definitions and measurements of variables as well as the data source utilized in this study. Section 4 presents results and related discussions. Section 5 summarizes the conclusions, discusses their implications for theory and managerial practice, and suggests possible directions for future research.

2. Literature Review and Theoretical Proposals

One specified industrial technology trajectory and set of internal procedures sees firms committing themselves to an incremental improvement of product and process and in turn leads to a breakthrough in innovation only when profit drops below a satisfactory level (Dosi, 1982; Nelson and Winter, 1982) or opportunities for technological change are seen (Dosi, 1982). A synthesis of both exogenous and endogenous perspectives should be in place to understand such a process of technological development (Rizzello, 2000). The process can be exogenous and derives from learning processes through imperfect imitation using the diffusion of industrial technological change (e.g., Nelson and Winter, 1982). It can also be endogenous and derives from a path dependent process of capability accumulation (Dosi and Kaniovski, 1994). Accordingly, the process of technological development is dominated by two mechanisms. On the one side, firms have to accumulate technological capabilities by learning with a path-dependent effect (Teece, 1986; Cohen and Levinthal, 1990; Malerba and Orsenigo, 1996; Breschiet al., 2000; Winter, 2000). On the other side, they have to keep their eyes on technological breakthroughs based on anticipation of technological change in order to survive the process of creative destruction (Tushman and Anderson, 1986; Anderson and Tushman, 1990; Henderson and Clark, 1990).

These two mechanisms both operate during the process of catch-up. Although latecomers do not necessarily copy the whole technological trajectory during catch-up, they usually turn to technological learning in order to accumulate technological capabilities, the process of which is path-dependent (Hobday, 1995; Cho et al., 1998; Mathews and Cho, 1999). Furthermore, in the case of technological learning, if the history of technological change in advanced countries is any guide, latecomers would have to experience a sense of crisis in order to adjust the orientation of technological development (Kim, 1999). Anticipation of technological change plays an important role in decision-making not only at the start when an industry faces entry opportunities but also at later stages when approaching the international frontier of technology (Li and Kong, 2006).

A firm's innovation and industrial technological change experience interplay caused by the above two mechanisms, according to evolutionary perspectives of innovation and technological change (e.g. Dosi, 1988; Malerba, 2007). It is not our purpose in this paper to analyze how this interplay occurs but rather to explain that a firm's technological development is determined by industrial technological change, whether incremental or radical. Accordingly, when one views catch-up as a form of firm-level technological development, patterns of catch-up will be seen as being shaped by the type of technological change. In what follows, we classify the catch-up process into three different patterns which are related to a new categorization of technological change and propose a theoretical model of the evolution of innovation along each specified pattern of catch-up.

2.1 A Categorization of Technological Change

Technological change is a "problem-solving" process which is guided by a prevailing technological paradigm similar to the scientific paradigm proposed by Kuhn (Dosi, 1982, 1988). The technological paradigm is a model or pattern which emerges from the solution of a given problem based on specified approaches to natural science and material technology. The technology paradigm involves not only a kind of dominant design (Utterback and Abernathy, 1975) but also a set of heuristics (Dosi, 1982, 1988) or routines (Nelson and Winter, 1982) which determine approaches to problem-solving.

A new technological paradigm is usually generated from technological breakthrough which not only reconfigures the knowledge base of science and technology (Nelson and Winter, 1982) but also brings about a new market structure due to Schumpeterian creative destruction (Dosi, 1982; Kamien and Schwartz, 1982; Breschi et al., 2000). A new technology paradigm means a kind of revolutionary change in technological development (Freeman, 1991). Following a specific technological trajectory defined by the technology paradigm, incremental change happens continuously until punctuated by another new technology paradigm (Dosi, 1982, 1988).

Theoretically, a particular technological paradigm could lead to many kinds of technological trajectories (Dosi, 1982, 1988) with only one surviving a harsh selection environment to become a dominant design (Utterback and Abernathy, 1975). However,, according to the theory of the industry life cycle, the dominant design is a phenomenon related to the concentration rate (Klepper, 1996). In other words, the dominant design works well only in those highly concentrated industries characterized by a particular production system and homogenous market demands: there is more than one design in industries characterized by high specialized and segmented market demands (Arora and Gambardella, 1998; Murman and Frenken, 2006; Marleba, 2007). In such industries another kind of technological change, i.e. disruptive change, plays a more important role than revolutionary change or incremental change in promoting substitution between various dominant designs and technological trajectories (Christensen, 1997; Christensen and Raynor, 2003).

To sum up, there are two points which need to be taken into consideration in categorizing technological change. First, technological change is a co-evolutionary process involving technology and market. Therefore, taking a perspective in which co-evolutionary processes inform a categorization of technological change has further implications for theoretical analyses and empirical studies (Freeman, 1991). Second, science-related factors or, alternatively, market-related factors are not the only source of technological change. Technological change is pushed by supply-side factors (Freeman, 1994) as well as pulled by demand-side factors (Mowery and Rosenberg, 1979). For these reasons, technological progress is a form of multi-dimensional change which involves technology and market (Tushman and Anderson, 1986).

Accordingly, we categorize technological change along both technology and market dimensions, taking a perspective based on a co-evolutionary process (Figure 1):

Figure 1 Types of Technological Change

The technology dimension of technological change relates to the method of technological performance improvement: such methods include improvement along the existing trajectory, a new trajectory, and a new paradigm. Improvement along the existing trajectory is characterized by incremental changes to a set of specified technological performances defined by a technological trajectory (Dosi, 1982). Creating a new trajectory means radical change to another set of technological performances which are defined by the same technology paradigm (Christensen and Raynor, 2003). Creating a new technology paradigm aims at solving wholly new technological problems based on radically different knowledge of science and technology (Dosi, 1982).

The market dimension of technological change is related to the market space where changes happen, including the existing market, the niche market, and the new market. The market space at a certain time can be divided into exploited niches and unexploited niches (Hannan and Freeman, 1977). A niche is characterized by a demand preference for specific technological functions (Adner, 2002). A set of niches can move into the existing market if their collective demand preference hits the mainstream. Otherwise those niches will evolve into a niche market characterized by non-mainstream demand preference. At a basic level, therefore, there is an overlap to some extent between the existing market and niche market in terms of demands for some technological functions. A new market is either unexploited or does not overlap with exploited market space in terms of demand preference (Lambkin and Day, 1989).

Each type of technological change can be defined both through its technology dimension and market dimension. An *incremental* change is defined as continuous improvement along an established technological trajectory with the aim of enhancing technological performance and market share in an existing market. A *disruptive* change is defined as either technology diversification or technology substitution with the aim of exploring niche markets. A *revolutionary* change is defined as a radical change to create a new technology paradigm with the aim of exploring a new market through competition for a dominant design.

It is noteworthy that there are no examples of any kind of technological change in the remaining four cells in the above figure. In instances of resource constraint, firms usually choose the most economic solution to a specified demand preference on the basis of a consideration of its input-output effect.

2.2 Patterns of Catch-Up and A Dynamic Model of The Evolution of Innovation

The three types of technology change indicate that there are both differences and congruence in the patterns of technology development. On the one hand, firms will seek their own unique pattern of technology development, due to different technological change opportunities and heterogeneous innovating behaviors (Nelson and Winter, 1982; Dosi, 1997). On the other hand, a common selection environment will lead various patterns of technology development towards a relatively homogeneous one in a manner analogous to that of the evolution of species (Jablonka and Ziman, 2000). For this reason, a dominant design will develop into a reality through the fermentation of various technological designs

(Utterback and Abernathy, 1975). Latecomers must face the same international technology regime (Lee and Lim, 2001) regardless of whether they choose methods based on the importing of technology or, alternatively, original research to catch up with technological leaders. Therefore, patterns of catch-up are not unlimited, due to the process of selection and survival involved in technological development. Furthermore, patterns of catch-up are completely constrained by specific opportunities for technological change.

On the basis of the above, we propose three patterns of catch-up related to categorization of technological change: *incremental*, *disruptive* and *revolutionary*.

Before analyzing the evolution of innovation along these three patterns of catch-up, we must explain first the dilemma between imitation and innovation, a central concern in the field of catch-up. Hobday (1995) conceived of the dilemma as a trade-off between simple activities and complex tasks or between simple learning and complex learning, during the process of technology development. In terms of technological novelty, the dilemma is more complicated as there are trade-offs within a wider range of innovation activities between, for example, radical innovation, major technological change, improvement of existing technology and imitation of existing technology (Chakrabarti, 1989). Many researchers have further argued for differences between continuous innovation activities and discontinuous innovation activities (e.g. Tushman and Anerson, 1986; Anderson and Tushman, 1990). Therefore, in descending order of technological novelty, innovative activities can be differentiated into breakthrough innovation and radical innovation followed by incremental innovation and imitation. We thus define the dilemma as involving trade-offs between innovation activities differentiated by the degree of technological novelty.

Based on this definition of the dilemma, we intend to analyze the way in which trade-offs among innovation activities change dynamically during the process of catch-up. We then examine each dynamic model of the evolution of innovation along the three patterns of catch-up and make related theoretical proposals.

An incremental pattern of catch-up is related to incremental technological change. Faced with a mature technological trajectory and existing market demands, latecomers usually enter the object industry by means of importing technology via technology licenses, OEM, technology contracts and so on (Bell and Pavitt, 1993; Hobday., 1995). To assimilate imported technologies, latecomers endeavor for an extended period to intensify technological learning efforts through the imitation of existing technologies (Perez and Soete, 1988; Nelson, 1991; Kim, 1997; Mathews, 2002, 2006). After building up enough technological capabilities, latecomers will transit from simple imitation to creative imitation or minor innovation (Lall, 1981; Kim, 1997). Due to loss of low-labor cost advantages and technology diffusions from other related industries, latecomers invest more and more in radical innovation to revise the dominant design as they approach the international technology frontier (Kim, 1997; Mathews and Cho, 1999; Mathews, 2002; Hobday et al., 2004). Finally, latecomers arrive at the stage of incremental innovation and remain there until the next cycle of technological change.

In general, there are four stages of the evolution of innovation on the incremental pattern of catch-up, including simple imitation, creative imitation, radical innovation, and incremental innovation (Figure 2):

Figure 2 Evolution of Innovation on the Incremental Pattern of Catch-up

----

In the first stage of *incremental* catch-up, latecomers usually start by importing technology and manufacture mature products through simple imitation. In the second stage, latecomers continue with technological learning via re-engineering. When domestic competition becomes increasingly severe, latecomers usually make heavy investments in engineering and product development. This helps them to acquire creative imitations or make minor innovations. It takes a considerable time for latecomers to arrive at the third stage. At this point, latecomers invest significant amounts into research activities to obtain radical innovations to allow them to deal with fierce competition from both domestic and international markets. The third stage usually involves diffusion of technological breakthroughs from other related industries. These technological breakthroughs help to prolong the life of the industry. When the industry becomes completely mature, latecomers enter the stage of incremental innovation, which aims at improving technological performance and lowering cost to receive as much profit as possible from former radical innovations. The level of technological novelty will not decrease significantly as latecomers have to invest more into next-generation technology at the same time as their incremental innovation. Accordingly, a theoretical hypothesis regarding the evolution of innovation on the *incremental* pattern of catch-up is as follows:

Hypothesis 1. The evolution of innovation in terms of technological novelty will follow an inverted U-shape on the incremental pattern of catch-up.

A *disruptive* pattern of catch-up is related to disruptive change. Faced with a high degree of diversified demands (Porter, 1983) or less/no demanding customers, latecomers can acquire industry entry via disruptive innovation without copying the existing dominant design (Christensen and Raynor, 2003). Due to the established advantage of competitive leaders in the mainstream market, it is advisable for latecomers to adopt a strategy of low-cost imitation at first in order to accumulate technological capabilities (Christensen et al., 1998; Lee and Lim, 2001; Adner, 2002). Then latecomers can initiate a new technological trajectory via disruptive innovation in the sense of radical change, and conduct long-term incremental innovations in the sense of continuous change to improve technological performances and cost structures (Christensen and Raynor, 2003). Ultimately, latecomers confront their competitive leaders in the mainstream market and compete for a dominant position through integrating breakthroughs from other related industries into a new dominant design (Kim, 1997; Levinthal, 1998). Generally, there are four stages in the evolution of innovation on the *disruptive* pattern of catch-up, including imitation, radical innovation, incremental innovation and breakthrough innovation (Figure 3):

Figure 3 Evolution of Innovation on the Disruptive Pattern of Catch-up

----

In the first stage of *disruptive* catch-up, latecomers are committed to simple imitation of the existing product design. Through such a window of opportunity to learn from the mainstream market, latecomers conduct technological learning very quickly (Christensen et al., 1998). In the second stage, latecomers turn to radical innovation quickly in order to establish a new cost structure and satisfy different demands of the technological function. In the third stage, latecomers transit to incremental innovation and invest more resources to improve product designs. It is thus a long-term process before latecomers can be said to hold their own in the mainstream market. In the final stage, latecomers bring breakthrough innovation into a new dominant design to compete for the position of market leader. Accordingly, a theoretical hypothesis regarding the evolution of innovation on the disruptive pattern of catch-up is as follows:

Hypothesis 2. The evolution of innovation in terms of technological novelty will follow an N-shape on the disruptive pattern of catch-up.

A *revolutionary* pattern of catch-up is related to revolutionary change. When there are breakthroughs in science and technology at the mature stage of the industry life cycle, those breakthroughs can be brought into breakthrough innovation to create a new technology paradigm (Dosi, 1982). Radical innovations in terms of product and process follow on to establish a dominant design, which is gradually improved through subsequent incremental innovations (Utterback and Abernathy, 1975; Tushman and Anerson, 1986; Anderson and Tushman, 1990). However, it is too difficult for latecomers to seize the "technology window" unless they have first built up basic manufacturing capabilities through imitating the latest process technologies (Perez and Soete, 1988; Hobday et al., 2004).

Accordingly, there are four rather than three stages of the evolution of innovation on the revolutionary pattern of catch-up: imitation, breakthrough innovation, radical innovation, and incremental innovation (Figure 4):

Figure 4 Evolution of Innovation on the Revolutionary Pattern of Catch-up

----

In the first stage of revolutionary catch-up, latecomers have to build up modern manufacturing capabilities through technological transformation as these cannot be obtained by the acquisition of mature product technology but rather require new processes and equipment (Perez and Soete, 1988). Firms next go through stages of breakthrough innovation, radical innovation, and incremental innovation as suggested by many researchers (e.g. Utterback and Abernathy, 1975; Tushman and Anerson, 1986; Anderson and Tushman, 1990). A theoretical hypothesis regarding the evolution of innovation on the revolutionary pattern of catch-up is as follows:

Hypothesis 3. The evolution of innovation in terms of technological novelty will follow an inverted U-shape on the revolutionary pattern of catch-up.

3. Methodology and Data

For some time, the dynamics of innovation have been studied on the basis of an assumed relationship to the stages of development of a firm. Utterback and Abernathy (1975) analyzed the relationship empirically by means of survey data relating to the pattern of innovation within a firm and the firm's characteristics: the stage of development of its production process and its chosen basis of competition. Based on a categorization of development stages according to their theoretical model, the authors test their hypotheses by calculating percentages of specified innovation within each stage rather than analysing the frequency of innovation.

We intend to carry out here an initial feasibility test of our model following a revision to the research design of Utterback and Abernathy. First, we classify samples by means of a categorization of technological change corresponding to the three types located along the abscissa and ordinate of Figure 1. Second, we gather data on the fraction of turnover derived from new products at the firm level, which reflects innovation performance within various levels of technological novelty. We then define a new variable, i.e. completeness of catch-up to the characteristics of the development stage, which is in turn calculated for each pattern of catch-up on the basis of both technological and market dimensions. Finally, we use the statistical method of curve estimation to analyze the evolution of innovation performance on the basis of completeness of catch-up.

3.1 Sample and Data

The questionnaire used was developed in three stages. First, we developed a rough version based on theoretical analysis. Second, we carried out three field case studies of firms to test separately the three patterns of catch-up in order to correct any issues with the theoretical design of our questionnaire. Some items, and particularly questions related to judgments regarding the patterns of catch-up were revised over several rounds of interviews. Finally, we pilot-tested the questionnaire with 23 firms from manufacturing sectors. By analyzing all 23 responses, we produced a final version of the questionnaire which modified several language issues.

With the questionnaire finalized, we visited the officer in charge of an industrial department of the Ministry of Science and Technology of the People's Republic of China. We had a face-to-face discussion regarding the details of the questionnaire and revised some minor aspects of style and language. Samples were then determined by considering two issues. The first consideration concerned the firms to be sampled. These were firms that have implemented an innovation via either product innovation or process innovation within the last three years, according to the OECD (2005) definition of an innovative firm. The second consideration concerned the geographical areas to which to send the questionnaires. Considering the officer's previous background, we chose seven Economic Technical Development Areas, covering four of the more developed areas including Zhejiang province, Jiangsu province, and Shandong province and three less developed areas including Sichuan province, Xinjiang and Neimongu autonomous regions. The survey was initiated in February 2008 and was completed in March 2008. We received 343 responses. The response rate could not be determined because of a lack of data on the number of questionnaires sent: the officer mentioned above took charge of the sending and receipt of all questionnaires and in fact experienced the same problem once questionnaires had been sent to the officers in charge of the seven Economic Technical Development Areas. These issues significantly affect our knowledge of the characteristics of respondents.

Of the 343 questionnaires received, 279 questionnaires were valid, with a validity rate of 81.3%. All questionnaires were completed by a director of technology or innovation department, as verified by data from the completed questionnaire. An outline of the sample is as follows. In terms of year of establishment, 62 firms or 22.2% were established after 2002, 130 or 46.6% between 1992 and 2001, 37 or 13.3% between 1978 and 1991, and 29 or 10.4% before 1977. In terms of industry distribution, according to the classification proposed by Pavitt (1984), 43 firms or 15.4% belong to supplier-dominated industries, 38 firms or 13.6% to specialized supplier industries, 45 firms or 16.1% to scale-intensive industries, 122 firms or 43.7% to science and technology-driven industries and 31 firms or 11.1% to information-intensive industries.

3.2 Classification of Sample and Innovation Performance

As discussed above, patterns of catch-up are determined by technological change which is characterized by changes along both technological and market dimensions. On this logic, we adopt two points of departure in our classification of patterns of catch-up. The first is based on the technological aspect and questions firms on the perceived objective and historical process of technology development. The second element concerns the market and questions firms on the perceived objective of market development and the types of market in which sampled firms compete. On the basis of these two sets of questions, all sampled firms are classified into three groups. The group with an *incremental* pattern of catch-up is composed of firms which use continuous improvement along an established technological trajectory, aiming at enhancing technological performance and market share in an existing market. The group with a *disruptive* pattern of catch-up is composed of firms which use either technology diversification or technology substitution, aiming at creating new technological trajectory and exploiting niche markets. The group with a *revolutionary* pattern of catch-up is composed of firms which create a new technology paradigm, aiming at obtaining new technology designs and exploring new markets.

Data on the fraction of turnover from new product (FTNP) were gathered at the firm level as evidence of the innovation performance of sampled firms. Classic research on the dynamics of technological innovation has taken the innovation rate (Utterback and Abernathy, 1975) or patents (Archilladelis et al., 1990) as indicators of innovation output. Other leading work has, however, utilized indicators of FTNP as a measure of innovation performance, being a measure widely used in large surveys such as the Community Innovation survey (CIS) based on the OECD Oslo Manual (Laursen and Salter, 2006). Considering both the inconsistent nature of definitions of the novelty of innovation and the difficulty of measuring innovation performance (Chakrabarti, 1989; Johannessen et al., 2001), we adopt the FTNP measure as this provides important information on product innovation and the degree of innovation of the enterprise (OECD, 2005). Although the FTNP measure exhibits some deficiencies in relation to process innovation, it is difficult to find better measures (Lawless and Anderson, 1996; Yam, et al., 2004; Osawa and Yamasaki, 2005).

Table 1 shows the distribution of the sample among the three groups and details descriptive statistics relating to FTNP. The group with a *revolutionary* pattern of catch-up exhibits the highest FTNP whilst there is little difference between the other two groups:

Table 1 Comparison of FTNP among Three Sample Groups

3.3 Calculating the Degree of Catch-up

As previously indicated, this research aims to take a different approach to previous research on the dynamics of technological innovation which, as discussed above, uses either time series analysis of patents (Archilladelis et al., 1990) or frequency analysis of specified stages of innovation (Utterback and Abernathy, 1975). Instead, we try to develop approximate curves to represent the evolution of innovation along each specified process of catch-up. With FTNP measuring innovation performance during the evolution of innovation, the remaining task is to understand how to measure the process of catch-up. Our literature review suggests that there are relatively few pieces of research regarding this problem. We therefore develop a new variable which aims to capture the completeness of catch-up along particular stages within the specified pattern of catch-up.

Catch-up is not only a matter of speed (Perez and Soete, 1988) but rather aims to promote the processes of both technology development and market competition (Lee and Lim, 2001; Park and Lee, 2006). Accordingly, the completeness of catch-up is defined here as the extent to which such a process of catch-up has been completed. On the one hand, the completeness of catch-up should be measured on both technology and market dimensions. According to basic innovation assumptions deriving from Schumpeter (Nelson and Winter, 1976; Nelson and Winter, 1982; Malerba and Orsenigo, 1996), technological change drives the co-evolution of market structure and technological performance on the basis of an interaction between the innovation of firms and changes in the industry (Tushman and Anderson, 1986; Dosi, 1988). Constrained by the international technology regime, catch-up has to take into account the effects of both technological development and market development (Lee and Lim, 2001). On the other hand, the degree of catch-up should be measured separately for each pattern of catch-up. On the basis of the effects of networked externalities, scale economies and irreversible innovation behaviors, the process of catch-up involves certain innovation choices and mutually exclusive paths (Dosi, 1982; Cohen, 1984; David, 1985; Arthur, 1996). Accordingly, under constraints of resource limitation and path-dependence, latecomers are unable to adopt two different patterns of catch-up simultaneously.

In summary, the degree of catch-up can be measured separately for each pattern on the basis of indicators which cover both technology and market dimensions. Using a 5-point Likert scale questionnaire, respondents were asked questions relating to growth of market share and technology improvement in order to assess the Completeness of Incremental Catch-up (CICU). Assessments of the Completeness of Revolutionary Catch-up (CRCU) involved questions relating to the exploration of new markets, the introduction of new technology and industry restructuring, issues suggested as important in several previous studies (Levin et al., 1985; Dosi and Orsenigo, 1988; Freeman and Perez, 1988; Dosi, 1988;

Anderson and Tushman, 1990; Klepper, 1996; Kim, 1997; Levinthal, 1998; Breschiet al., 2000; Van den Ende and Dolfsma, 2005; Leiponen and Drejer, 2007). Questions about the Completeness of Disruptive Catch-up (CDCU) concerned the exploitation of less-demanding markets and technology diversification, as suggested by the theory of disruptive innovation (Christensen and Rosenbloom, 1995; Christensen, 1997; Christensen and Raynor, 2003). Table 2 details descriptive statistics for these indicators:

Table 2 Descriptive Statistics of Completeness of Three Patterns of Catch-up

----

Restricting the number of indicators (i.e. to less than three) would prevent use of the factor reduction method to calculate an aggregate measure of the completeness of catch-up. Following research into decision analysis (e.g. Levy and Delih, 1994; Myun et al., 1996) we use Shannon's information measure (Shannon 1948; Jaynes 1957) to derive aggregation rules for combining two or more indicators into a single aggregated prediction that appropriately reflects any dependence that may exist among those indicators. Three steps are taken to calculate entropy and the related weight of each indicator as follows:

First, transform the observed value of every measure x_{ij} into a percentage p_{ij} using formula (1):

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, \quad i = 1,2,\cdots,m;\ j = 1,2,\cdots,n \qquad (1)$$

Second, define the entropy of measure j using formula (2):

$$H_j = -k\sum_{i=1}^{m} p_{ij} \ln p_{ij},\ j = 1,2,\cdots,n \qquad (2)$$

In formula (2), $k = \frac{1}{\ln m}$ is used to ensure $H_j = 1$ when every p_{ij} equals to 1/m. Additionally, it is assumed $p_{ij} \ln p_{ij} = 0$, when $p_{ij} = 0$, to ensure $H_j \in [0,1]$.

Finally, the weight of measure j is calculated using formula (3).

$$\omega_{\sigma j} = \frac{1-H_j}{\sum_{j=1}^{n}(1-H_j)} = \frac{1-H_j}{n-\sum_{j=1}^{n}H_j}, \qquad j = 1,2,\cdots,n \tag{3}$$

In formula (3), $\omega_{\sigma j} \in [0,1]$, and $\sum_{j=1}^{n} w_{\sigma j} = 1$.

Applying the above three steps, Table 3 details the calculated results for entropy and weight for each indicator calculated:

Table 3 Indicator Weight for Calculating Completeness of the Three Patterns of Catch-up

----

4. Results and Discussion

In order to derive a curve estimation of the evolution of innovation on the different patterns of catch-up, a regression model was chosen on the basis of the results of a scatter plot, taking FTNP as the y-axis and completeness of catch-up as the x-axis. The results of consequent hypothesis tests and related discussions are presented below.

4.1 The Evolution of Innovation follow the Incremental Pattern of Catch-up

According to the model summary and ANOVA results of quadratic model estimates of the evolution of innovation on the *incremental* pattern of catch-up, a quadratic model is a suitable model for curve estimation of the evolution of innovation on the *incremental* pattern of catch-up.

The results of curve estimation using a quadratic model can be found below in Table 4. We find strong support for the hypothesis that the evolution of innovation on the *incremental* pattern of catch-up is curvilinear, i.e. taking an inverted U-shape (Hypothesis 1). This is firstly because the parameter for CICU is significant and positive for FTNP, showing that CICU is an important factor in explaining FTNP. Second, the parameter for CICU-squared is significant as well, showing that when CICU is very high in the later stages of *incremental* catch-up there is a decreasing trend in FTNP. Finally, the parameter for CICU is 1.164 and for CICU squared is -.715, which indicates that the inverted U-shape is characterized by an incremental ascent stage followed by a diminishing descent stage.

Table 4 Coefficients of Quadratic Curve Estimation Model of Incremental Catch-up (N=136)

However, although the model predicts both ascending and descending trends, the results only allow us to estimate a very rough curve of the evolution of innovation on the *incremental* pattern of catch-up. From Figure 5, two important turning points in the scatterplots, i.e. T_1 and T_2, can be roughly discerned in the curve. As a result, the process of incremental catch-up can be divided into three stages. Innovation in the first stage is characterized by imitation and minor innovation, with the lowest level of overall innovation performance. At this stage, the sampled firms endeavor to accumulate technological capabilities through technological learning. In the second stage, sampled firms turn their efforts towards radical innovation, which slowly leads innovation performance towards a peak. Finally, the process enters a third stage centered on incremental innovation with lower innovation performance than at the second stage yet remaining at a higher level than that of the first stage. The reason why innovation performance does not drop significantly may lie in the heavy investments made by latecomers in next-generation technology or in a radically new technology paradigm as a result of limits in existing technologies.

Figure 5 The Evolution of Innovation on the Incremental Pattern of Catch-up

----

4.2 The Evolution of Innovation follow the Disruptive Pattern of Catch-up

The model summaries and ANOVA results for both linear and cubic model estimations of the evolution of innovation on the *disruptive* pattern of catch-up indicate that both models are suited to a curve estimation of the evolution of innovation. A possible prediction is that the curve will be significant for the CDCU parameter but insignificant for CUCU squared or cubic.

In Table 5 the results of regression analysis using these two models show that the coefficient of CDCU is positive and significant but that both coefficients of CDCU squared and cubic are not significant even at the 0.1 level. This supports our prediction mentioned above. On the basis of the results of the regression analysis, we cannot find any support for our hypothesis that the evolution of innovation on the *disruptive* pattern of catch-up will be a curvilinear N-shape (Hypothesis 2). Firstly, the parameter for CDCU is significant and positive for FTNP, showing that CDCU is an important factor in explaining FTNP. Secondly, the parameters for CICU squared and cubic are insignificant, showing that when CICU grows at later stages of *disruptive* catch-up there are no curvilinear trends in FTNP. Therefore, from a statistical perspective, we have to conclude that Hypothesis 2 is incorrect and find that evolution on the *disruptive* pattern of catch-up exhibits only a positive linear relationship between CDCU and FTNP.

Table 5 Coefficients of Linear and Cubic Curve Estimation of Disruptive Catch-up (N=60)

To analyse further the reasons why the evolution of innovation on the *disruptive* pattern of catch-up is linear rather than cubic, we attempt to find two approximate turning points on the basis of scatterplots, i.e. T_1 and T_2. The evolution of innovation amongst sampled firms on the *disruptive* pattern of catch-up appears to adopt an ascending pattern until T_1 but then quickly descends to T_2 before ascending quickly once more. Accordingly, we can propose three speculative interpretations as follows. First, sampled firms relied on a strategy of imitation and low-price competition for too long a period since entry into the industry starts by means of exploitation of less-demanding segments. Second, sampled firms may invest too few resources into radical innovation of product design and cost structures to initiate a new technological trajectory. Third, sampled firms may not transit to compete in mainstream markets owing either to deficient product design or a sub-optimal cost structure as a result of insufficient investment into incremental innovation to improve their radical innovation. Based on these considerations, we argue that latecomers will be pushed out of mainstream competition over a dominant design into peripheral niche market segments if the possibilities mentioned above occur.

Figure 6 The Evolution of Innovation Curve on the Disruptive Pattern of Catch-up

----

4.3 The Evolution of Innovation Follow the Revolutionary Pattern of Catch-up

According to the model summary and ANOVA results of a quadratic model estimation of the evolution of innovation on the *revolutionary* pattern of catch-up, a quadratic model is a suitable basis for curve estimation of the evolution of innovation on the *revolutionary* pattern catch-up.

Table 6 shows the results of curve estimation using a quadratic model. We find strong support for the hypothesis asserting that the evolution of innovation on the revolutionary pattern of catch-up is curvilinear, i.e. takes an inverted U-shape (Hypothesis 3). Firstly, the parameter for CRCU is significant and positive for FTNP, showing that CRCU is an important factor in explaining FTNP. Secondly, the parameter for CRCU squared is also significant but this time negative, showing that when CRCU is very high in the later stages of *revolutionary* catch-up there are decreasing trends for FTNP. Lastly, the parameter for CRCU is 1.589 and for CRCU squared is -1.237, which indicates that the inverted U-shape is characterized by a stage of incremental ascent followed then by an incremental descent stage. It is worth noting that comparison of parameters suggests that the curved shape of the evolution of innovation on the *revolutionary* pattern of catch-up is sharper than that on the *incremental* pattern of catch-up, although the two patterns have a resemblance in the sense of sharing similar curved patterns.

Table 6 Coefficients of the Quadratic Curve Estimation Model of Revolutionary Catch-up (N=83)

To explore further the characteristics of the approximate curve of the evolution of innovation on the *revolutionary* pattern of catch-up, two approximate important turning points, i.e. T_1 and T_2, can be discerned on the basis of the scatter plots shown in Figure 7. Therefore, the process of *revolutionary* catch-up can be divided into three stages. In the first stage, innovation is centered on technological transformation to accumulate manufacturing capabilities, with the lowest level of innovation performance but higher speed of growth. In the second stage, innovation performance rises consistently and peaks, which is different from the theoretical analysis previously mentioned. This implies that latecomers need not necessarily go through a process of breakthrough innovation followed by radical innovation when adopting the revolutionary pattern of catch-up but can rather create a new technology paradigm by industrializing new science and technology from other industries through continuous radical innovation. In the last stage, innovation performance drops off quickly with emphasis on incremental innovation to acquire returns from improving technological quality and performance.

Figure 7 The Evolution of Innovation Curve on the Revolutionary Pattern of Catch-up

----

5. Conclusions

This paper attempts to explore the evolution of innovation within three patterns of catch-up, using statistical analyses of curve estimation from survey data collected in China. The results support two hypotheses regarding evolution of innovation curves within both *incremental* catch-up and *revolutionary* catch-up but contradicts our hypothesis regarding the evolution of innovation on the *disruptive* pattern of catch-up. The evolution of innovation on the *incremental* pattern of catch-up slowly moves to a peak as many former studies suggested, then drops off to a higher level than the initial level. The shape of the curve of the evolution of innovation for *revolutionary* catch-up is in general agreement with what many works have suggested from a theoretical perspective but it indicates that there is continuous *radical* innovation during the creation of a new technology paradigm rather than *breakthrough* innovation followed by *radical* innovation. The evolution of innovation on the *disruptive* pattern of catch-up is more of a linear process than a cubic process, which contradicts the hypothesis statistically. However, the scatter plots do indeed show a process which appears as a peak followed by a valley.

To sum up, the results suggest that deriving a higher fraction of turnover from new products does not necessarily lead to higher performance in catch-up and latecomers have to solve the dilemma between imitation and innovation in line with the stages of development of technological change no matter what pattern of catch-up they follow. Results from the study have several managerial implications. Firstly, it is very important for latecomers following the *incremental* pattern of catch-up to invest more into next-generation technologies based on anticipation and forecasts of technological change when approaching the international frontier of technology. Secondly, for latecomers following the *disruptive* pattern of catch-up, heavy investment into product design and cost structure is crucial, especially when they are facing the transition to a new technological trajectory after completing their exploitation of less-demanding market segments. Finally, technological transformation plays a fundamental role in the accumulation of manufacturing capabilities for *revolutionary* catch-up. Furthermore, creating a new technology paradigm via industrialization and the science and technology breakthroughs of other industries should be a feasible strategic choice for firms adopting the *revolutionary* catch-up route.

Although the statistical analyses based on survey data used by this paper are inferior to time-series analyses and history analyses of specific industries, the work nevertheless contributes to the field of catch-up research in three respects. Firstly, the categorization of technological change including the incremental, disruptive and revolutionary forms, supports a comprehensive basis for the study of technological development through the reduction of confusions within former categorizations such as radical vs. incremental, continuous vs. discontinuous, or creative-destroying vs. creative-enhancing. Secondly, this paper proposes a comprehensive framework for the study of catch-up and perspectives of technological change. Finally, this paper contributes to the field of catch-up by proposing comprehensive sets of catch-up patterns, replacing former types such as path-following, path-skipping, and path-creating.

Acknowledgement:

The authors would like to thank National Natural Science Foundation of China (Grant No. 70810107021) for financial support and to seminar and conference participants at Oxford University and the 21st Chinese Economic Association (Europe) Annual Conference for helpful comments.

References

Adner, R., 2002. When are technologies disruptive? a demand-based view of the emergence of competition. Strategic Management Journal. 23 (8), 667-688.

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

Archilladelis, B., Schwarzkopf, A., Cines, M., 1990. The dynamics of technological innovation: the case of the chemical industry. Research Policy. 19,1-34.

Arora, A., Gambardella, A., 1998. Evolution of Industry Structure in the Chemical Industry. Wiley, New York.

Arthur, B., 1996. Increasing returns and the new world of business. Harvard Business Review. July/August, 100-109.

Bell, M., Pavitt, K., 1993. Technological accumulation and industrial growth: contrasts between developed and developing countries. Industrial and corporate change. 2(1), 157-210.

Breschi, S. Malerba, F., Orsenigo, L., 2000. Technological regimes and schumpeterian patterns of innovation. The Economic Journal. 110 (463), 388-410.

Chakrabarti, A. K., 1989. Technology indicators: concept issues and measurement problems. Journal of Engineering and Technology Management. 6, 99-l 16.

Cho D. S., Kim, D. J. and Rhee, D. K. Latecomer Strategies: Evidence from the Semiconductor Industry in Japan and Korea. Organization Science, 1998, 9(4): 489-505.

Christensen, C. M., 1997. The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail. Harvard Business

School Press, Boston, Massachusetts.

Christensen, C. M., Raynor, M. E., 2003. The Innovator's Solution: Creating and Sustaining Successful Growth. Harvard Business School Press, Boston, Massachusetts.

Christensen, C. M., Rosenbloom, R. S., 1995. Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network. Research Policy. 24 (2), 233-257.

Christensen, C. M., Suárez, F. F., Utterback, J. M., 1998. Strategies for survival in fast-changing industries. Management Science. 44(12), 207-220.

Cohen, A. J., 1984. Technological change as historical process: the case of the U.S. pulp and paper industry 1915-1940. The Journal of Economic History. 44(3), 75-799.

Cohen, W. M., Levinthal, D. A., 1990. Absorptive capacity: a new perspective on learning and innovation. Administrative Science Quarterly. 35(1), 128-152.

David, P., 1985. Clio and the economics of QWERTY. American Economics Review. 75, 332-337.

Dosi, G., 1997. Opportunities, incentives and the collective patterns of technological change. The Economic Journal. 107 (444), 1530-1547.

Dosi, G., 1988. Sources, procedures, and microeconomic effects of innovation. Journal of Economic Literature. 26(3), 1120-1171.

Dosi, G., 1982. Technological paradigms and technological trajectories: suggested interpretation of the determinants and directions of technical. Research Policy. 11(3), 147-162.

Dosi G., Kaniovski Y., 1994. On `badly behaved' dynamics. Journal of Evolutionary Economics. 4, 93-123.

Dosi, G., Orsenigo, L., 1988. Coordination and transformation: an overview of structures, behaviors and change in evolutionary environments, in: Dosi, G., Freeman, C., Nelson, R., et al. (Eds.), Technical Change and Economic Theory. Printer publishers, London and New York, pp. 13-37.

Freeman, C., 1994. The economics of technical change. Cambridge Journal of Economics. 18, 463-514.

Freeman, C., 1991. Innovation, changes of techno-economic paradigm and biological analogies in economics. Revue économique. 42(2), 211-231.

Freeman, C., Perez, C., 1988. Structural crises of adjustment: business cycles and investment behavior, in: Dosi, G., Freeman, C., Nelson, R., et al. (Eds.), Technical Change and Economic Theory. Printer publishers, London and New York, pp. 38-66.

Hannan, M. T., Freeman, J., 1977. The population ecology of organizations. American Journal of Sociology. 82 (5), 929-964.

Henderson, R. M., Clark, K. B., 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. Administrative Science Quarterly. 31(1), 9–30.

Hobday, M., 1995. East Asian latecomer firms learning the technology of electronics. World Development. 23(7), 1171-1193.

Hobday, M., Rush, H., Bessant, J., 2004. Approaching the innovation frontier in Korea: the transition phase to leadership. Research Policy. 33, 1433–1457.

Jablonka, E. & Ziman, J., 2000. Biological evolution: processes and phenomena, in: Ziman, J. (Eds.), Technological Innovation as an Evolutionary Process. Cambridge University Press, Cambridge, pp.13-26.

Jaynes, E. T., 1957. Information theory and statistical mechanics. Physics Review. 106(Part I), 620-630, 108 (Part II), 171-190.

Johannessen, J. A., Olsen, B., Lumpkin, G.T., 2001. Innovation as newness: what is new, how new, and new to whom? European Journal of Innovation Management. 4(1), 20-31.

Kamien, M. I., Schwartz, N. L., 1982. Market Structure and Innovation. Cambridge University Press, Cambridge.

Kim, L., 1999. Building technological capability for industrialization: Analytical frameworks and Korea's experience. Industrial and Corporate Change. 8(1), 111-136.

Kim, L., 1997. Imitation to Innovation: The Dynamics of Korea's Technological Learning. Harvard Business School Press, Boston.

Klepper, S., 1996. Entry, exit, growth and innovation over the product life cycle. American Economic Review. 86(3), 562-83.

Lall, S., 1981. Indian technology exports and technological development. Annals of the American Academy of Political and Social Science. 458, 151-162.

Lambkin, M, Day, G. S., 1989. Evolutionary processes in competitive markets: beyond the product life cycle. The Journal of Marketing. 53(3), 4-20.

Laursen, K., Salter, A., 2006. Open for innovation: the role of openness in explaining innovation performance among U. K. manufacturing firms. Strategic Management Journal. 27, 131-150.

Lawless, M. W., Anderson, P. C., 1996. Generational technological change effects of innovation and local rivalry on performance. The Academy of Management Journal. 39(5), 1185-1217.

Lee, K., Lim, C., 2001. Technological regimes, catching-up and leapfrogging: findings from Korean industries. Research Policy. 30,459–483.

Leiponen, A., Drejer, I., 2007. What exactly are technological regimes: intra-industry heterogeneity in the organization of innovation activities? Research Policy. 36, 1221–1238.

Levin, R. C., Cohen, W. M., Mowery, D. C., 1985. R&D appropriability, opportunity, and market structure: new evidence on some schumpeterian hypotheses. The American Economic Review. 75(2), 20-24.

Levinthal, D. A., 1998. The slow pace of rapid technological change: gradualism and punctuation in technological change. Industrial and Corporate Change. 7(2), 217-247.

Levy, W. B., Delih, H., 1994. Maximum entropy aggregation of individual opinions. IEEE Transactions on Systems, Man and Cybernetics. 24, 606-613.

Li, A. Y. G., Kong, W. H., 2006. Innovation, imitation and entrepreneurship. The Singapore Economic Review. 51(2), 147–173.

Malerba, F., 2007. Innovation and the dynamics and evolution of industries: progress and challenges. International Journal of Industrial Organization. 25(4), 675-699.

Malerba, F., Orsenigo, L., 1996. Schumpeterian patterns of innovation are technology-specific. Research Policy. 25, 451-478.

Mathews, J. A., 2006. Catch-up strategies and the latecomer effect in industrial development. New Political Economy. 11 (3), 313-335.

Mathews, J. A., 2002. Competitive advantages of the latecomer firm: a resource-based account of industrial catch-up strategies. Asia Pacific Journal of Management. 19, 467–488.

Mathews. J. A., Cho, D. S., 1999. Combinative capabilities and organizational learning in latecomer firms: the case of the Korean semiconductor industry. Journal of World Business. 34 (2), 139-156.

Mowery D., Rosenberg N., 1979. The influence of market demand upon innovation: a critical review of some recent empirical studies. Research Policy. 8(2), 102-153.

Murmann, J. P., Frenken, K., 2006. Toward a systematic framework for research on dominant designs, technological innovations, and industrial change. Research Policy. 35, 925-952.

Myung, I. J., Ramamoorti, S., Bailey, A. D. Jr., 1996. Maximum entropy aggregation of expert predictions. Management Science. 42(10), 1420-1436.

Nelson, R.R., 1991. Why do firms differ, and how does it matter? Strategic Management Journal. 12, 61-74.

Nelson, R. R., Winter, S. G., 1982. The schumpeterian tradeoff revisited. The American Economic Review. 72 (1), 114-132.

Nelson, R. R., Winter, S. G., 1976. Simulation of schumpeterian competition. The American Economic Review. 67 (1), 271-276.

OECD, 2005. Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data. A joint publication of OECD and Eurostat (Third Edition), Paris.

Osawa, Y., Yamasaki, Y., 2005. Proposal of industrial research and development performance indices. R&D Management. 35(4), 455-461.

Park, K. H., Lee, K., 2006. Linking the technological regime to the technological catch-up: analyzing Korea and Taiwan using the US patent data. Industrial and Corporate Change. 15 (4), 715-753.

Pavitt, K., 1984. Sectoral patterns of technical change: towards a taxonomy and a theory. Research Policy. 13, 343-373.

Perez, C., Soete, L., 1988. Catching up in technology: entry barriers and windows of opportunity, in: Dosi, G., Freeman, C., Nelson, R., et al. (Eds.), Technical Change and Economic Theory. Printer publishers, London and New York, pp. 458-479.

Porter, M. E., 1983. The technological dimension of competitive strategy, in: Rosenbloom, R. S. (Eds.), Research on Technological Innovation, Management and Policy. CT: JAI Press, Greenwich.

Rizzello, S., 2000. Economic change, subjective perception and institutional evolution. Metroeconomica. 51 (2), 127–150.

Shannon, C. E., 1984. A mathematical theory of communication. Bell Syst. Tech. J. 27, 379-423.

Teece, D. J., 1986. Profiting from technological innovation. Research Policy. 15(6), 285-306.

Tushman, M.L., Anderson, P., 1986. Technological discontinuities and organizational environments. Administrative Science Quarterly. 31, 439–465.

Utterback, J. M., Abernathy, W. J., 1975. A dynamic model of process and product innovation. The International Journal of Management Science. 3(7), 639- 656.

Van den Ende, J. V. D., Dolfsma, W., 2005. Technology push, demand pull and shaping of technological paradigms-patterns in the development of computing technology. Journal of Evolutionary Economics. 15, 83-99.

Winter, S. G., 2000. The satisfying principle in capability learning. Strategic Management Journal. 21 (10/11), 981-996.

Yam, R. C. M., et al., 2004. An audit of technological innovation capabilities in Chinese firms: some empirical findings in Beijing, China. Research Policy. 33, 1123–1140.

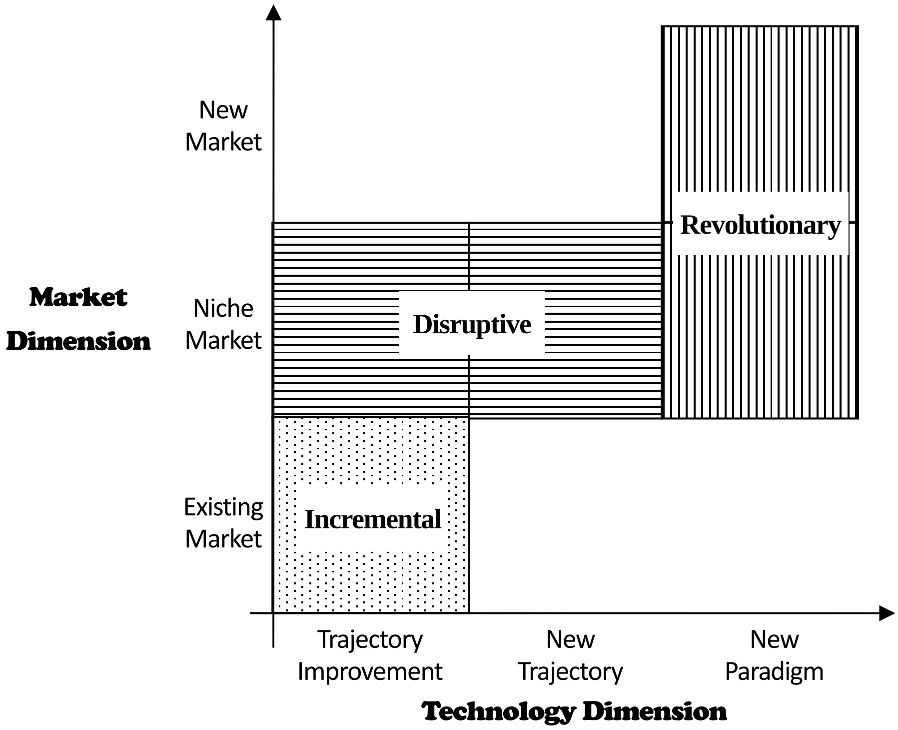

Figure 1 Types of Technological Change

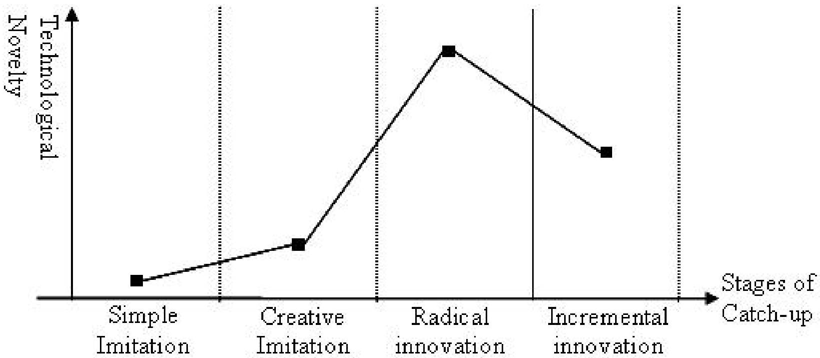

Figure 2 Evolution of Innovation on the Incremental Pattern of Catch-up

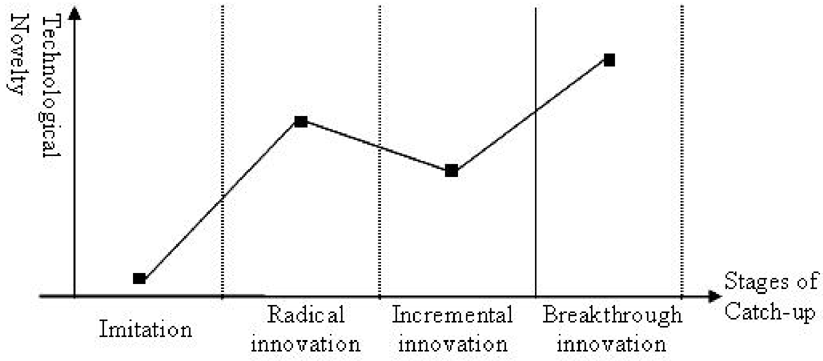

Figure 3 Evolution of Innovation on the Disruptive Pattern of Catch-up

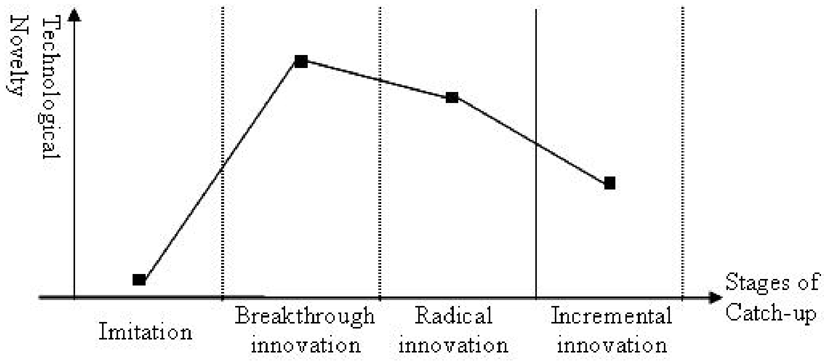

Figure 4 Evolution of Innovation on the Revolutionary Pattern of Catch-up

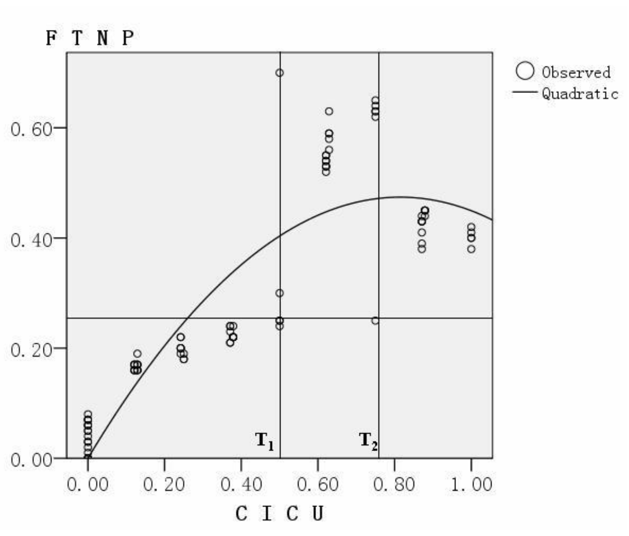

Figure 5 The Evolution of Innovation on the Incremental Pattern of Catch-up

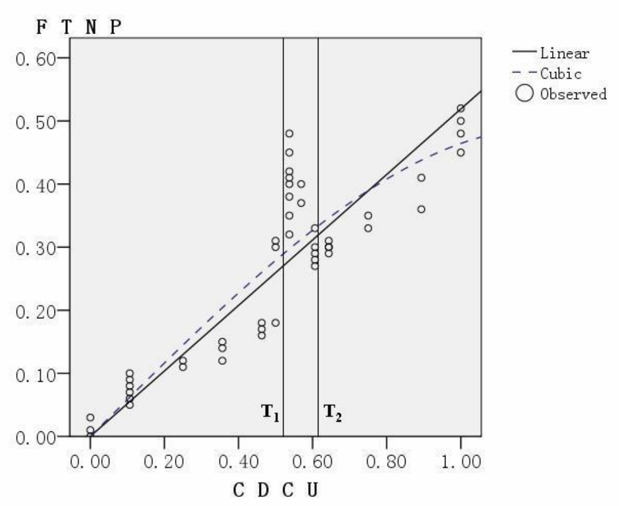

Figure 6 The Evolution of Innovation Curve on the Disruptive Pattern of Catch-up

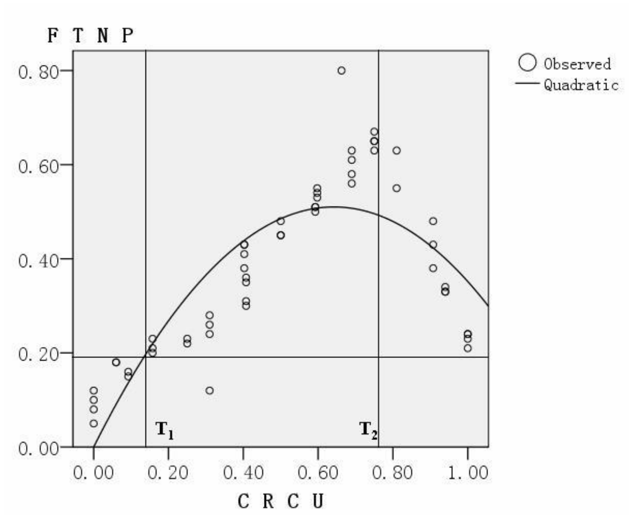

Figure 7 The Evolution of Innovation Curve on the Revolutionary Pattern of Catch-up

Table 1 Comparison of FTNP among Three Sample Groups

Catch-up Pattern	Indicator of Innovation Performance	N	Min	Max	Mean	S.D.
Incremental	FTNP (average for three latest years)	136	.00	.70	.2869	.19518
Disruptive		60	.00	.48	.2577	.13810
Revolutionary		83	.05	.80	.3758	.18206

Table 2 Descriptive Statistics of Completeness of Three Patterns of Catch-up

Variable	Indicator	N	Min	Max	Mean	S.D.
CICU	Market Share Growth	136	1.00	5.00	2.8487	1.33809
	Technology Improvement		1.00	5.00	2.7647	1.35738
CDCU	Exploitation of Less-Demanding Markets	60	1.00	5.00	3.1154	1.16575
	Technology Diversification		1.00	5.00	3.0769	1.34085
CRCU	New Market Exploration	83	1.00	5.00	3.2329	1.33874
	New Technology Introduction		1.00	5.00	3.0959	1.23788
	Industry Restructuring		1.00	5.00	3.3200	1.20987

Table 3 Indicator Weight for Calculating Completeness of the Three Patterns of Catch-up

Variable	Measure	Entropy	Weight
CICU	Market Share Growth	0.9718	0.4834
	Technology Improvement	0.9699	0.5166
CDCU	Exploitation of Less-Demanding Markets	0.9723	0.3928
	Technology Diversification	0.9738	0.3714
CRCU	New Market Exploration	0.9833	0.2358
	New Technology Introduction	0.9727	0.5703
	Industry Restructuring	0.9794	0.4297

Table 4 Coefficients of Quadratic Curve Estimation Model of Incremental Catch-up (N=136)

Dependent variable	FTNP	
Independent variable	Coefficients	Std. Error
CICU	1.164***	.072
CICU**2	-.715***	.090
R^2	0.929	
F statistics	614.054***	

Values in parentheses are t-statistic values for the estimated coefficients.

***, **, * denote statistically significant coefficients at 1%, 5% and 10% levels of significance.

Table 5 Coefficients of Linear and Cubic Curve Estimation of Disruptive Catch-up (N=60)

Model	Linear		Cubic	
Dependent variable	FTNP		FTNP	
Independent variable	Coefficients	Std. Error	Coefficients	Std. Error
CDCU	.519*** (28.676)	.018	.584*** (2.735)	.213
CDCU**2	-	-	.016 (.027)	.618
CDCU***3	-	-	-.136 (-.323)	.420
R^2	.946		.949	
F statistics	822.327***		292.438***	

Values in parentheses are t-statistic values for the estimated coefficients.

***, **, * denote statistically significant coefficients at 1%, 5% and 10% level of significance.

Table 6 Coefficients of the Quadratic Curve Estimation Model of Revolutionary Catch-up (N=83)

Dependent variable	FTNP	
Independent variable	Coefficients	Std. Error
CRCU	1.589*** (17.266)	.092
CRCU**2	-1.237*** (-10.805)	.114
R^2	.939	
F statistics	427.677***	

Values in parentheses are t-statistic values for the estimated coefficients.

***, **, * denote statistically significant coefficients at 1%, 5% and 10% level of significance.