Technological innovation from imitation in latecomer firms: evidence from China's auto firms

Abstract

Despite the significant research progress in the field of technological innovation relevant to developing countries, there is little literature concerning China's auto sector, which is now the largest automotive production and sales market in the world. The main purpose of this paper is to describe the firm-level process from imitation to innovation of indigenous auto firms in China, trying to generalize a hybrid model of technological innovation. Through a multi-case study, some findings are concluded: Chinese auto firms don't follow the catching-up models happened in other newly-industrializing economies (NIEs); two main differences exist between China's state-owned enterprises (SOEs) and private companies which showed on technological efforts and achievements; and these prove that learning is an important factor to achieve technological catching-up.

Keywords: Technological innovation; Imitation; Catching-up; Auto firms; China

1. Introduction

Ever since 1980s, researchers have paid great attention to the technological innovation process in latecomer firms due to the fast catching-up of NIEs in East and South-East Asia in getting economic achievements. Several technological innovation studies have been brought up based on empirical research in different industries such as semiconductor, automobile, and telecom. These studies have identified different stages of accumulation from the acquisition of foreign technology to the gradual building up of technological innovation that allowed some firms to reach the technological frontier, and even develop technological leadership in certain areas (e.g. Amsden, 1989; Hobday, 1994, 1995; Jin and von Zedtwitz, 2008; Kale and Little, 2007; Kim, 1980, 1997, 2001; Lee et al., 1988; Prahalad and Mashelkar, 2010).

In addition, researchers find that technological learning mainly starting from imitation helps companies develop products and enhance their technological capabilities (e.g. Bolton, 1993; Hobday, 1995; Kim, 1997; Lieberman and Asaba, 2006; Nelson, 2006). With regarding to this learning process from imitation to technological innovation, some scholars argue that learning process is comprised of acquisition, assimilation, and improvement (Kim, 1997), as well as several different kinds of imitative learning process such as production, design, R&D (Amsden, 1989); original equipment manufacturer (OEM), original design manufacturer (ODM), original brand manufacturer (OBM) (Hobday, 1995); initiation, internalization, generation (Lee et al., 1988).

Despite the significant and outstanding research progress achieved in the field of technological innovation concerning NIEs, the following two issues are rarely treated: how the technological innovation process occurred in China's auto firms? At the firm level, what are the similarities and differences of technological innovation mode between other NIEs and China's auto firms who also started from imitation at an early stage?

Ever since the initial introduction of former Soviet Union technology, China's auto

industry has passed fifty years. Throughout the process, regardless of First Automobile Works (FAW) and Shanghai Automotive Industry Corporation (SAIC), the traditional auto SOEs, or GEELY and BYD AUTO, the emerging private companies, all have gone through a road from imitation to innovation. Just like many latecomer firms of NIEs in Asian, imitation plays an important role in improving firms' technological capability, which not only help to obtain the lower level of technological capability, namely production capability, also the higher level, which is innovation capability (Xie, 2004). But existing research cannot explain the polarization phenomenon of China's auto companies: SOEs embarked technology acquisition through joint ventures (JVs), but a lot of learning still started from scratch. This is in sharp contrast to emerging private auto companies, which have gradually captured innovation capability from imitation.

The purposes of this study include three aspects: to explain how China's auto firms realize technological innovation from imitation through comparative analysis of SOEs and private auto firms; to find the similarities and differences of firms' technological innovation mode between China and other NIEs; and be a complement for technology innovation mode of latecomer firms, which can be expanded to other developing countries and contribute to the theoretical community.

This paper proceeds as follows. Following this introduction the next section summarizes the results and progress of academia on the innovation mode of latecomer firms; in Section 3, method and sources of data are described. Section 4 shows findings of comparative research of the two categories companies, analyzing and summarizing the characteristics and differences of SOEs and private enterprises from imitation to innovation, and the similarities and differences of firms' technological innovation mode between China and other NIEs. The conclusions provide a summary of the main findings and limitations of this article.

2. Literature review

2.1.Technological innovation in latecomers' catching-up

In general point of view, technological trajectory evolution of developed countries is made of three phases: turbulent period when exploring the radical innovation; transition period when dominant design appears, stable period when incremental innovation dominant (Utterback and Abernathy, 1975). According to Kim's (1980, 1997) research, technology development in Korea seems to follow the evolution of the reverse order, a model of acquisition, assimilation and improvement, obtaining mature technology from the developed countries.

Lee et al. (1988) expand Kim's (1980, 1997) model, and focus on technology transfer from developed to developing countries. They think that the above-mentioned three stages of technological trajectory in developing countries not only happen in stable period on mature technology, but in the transition and turbulent period of growth and emerging technologies. Hobday (1994, 1995) confirms this general reversal process of electronics in four dragons: Korea, Singapore, Hong Kong and Taiwan, denoting that this process is analyzed in terms of interacting technology and market transition from OEM, to ODM and OBM. Lee and Lim (2001) extend this reverse model by postulating the possibility of stage skipping opportunities. Developing Countries need to get rid of dependence on the path of developed countries to achieve true catching-up, especially when the technology trajectory changes, to seize the window of opportunity to leapfrog to catch up (Gao, 2003; Perez and Soete, 1988). Later, Forbes (2008) sketches the gradient picture from the followers to technology innovators as: learning to produce, learning to produce efficiently, learning to improve a product, learning to develop new products, learning to develop new technologies, and becoming the technology leader.

Many scholars also did a lot of empirical work on technological innovation catching-up process based on the aforementioned research, such as that of Fan (2006) on telecom-

equipment industry, Kale and Little (2007) on pharmaceutical industry, Liu (2010) on IT industry, Mu and Lee (2005) on telecommunication industry, Xie and Wu (2003) on color television (CTV) firms. Some R&D practices observed in Chinese firms appear to be different from Kim's (1980, 1997) model. Based on four in-depth cases studies set in Chinese mobile phone industry, Jin and von Zedtwitz (2008) hypothesize a complementary stage in Kim's (1980, 1997) model, and those stages can be traversed concurrently.

These studies provide a useful approach to understanding technological innovation catching-up in developing countries and the basis for further detailed research on firm-level innovation management (Hobday, 2005).

2.2.Transition from imitation to innovation: learning process

In developed countries, technological innovation realizes mainly through learning by R&D (Cohen and Levinthal, 1989) and then extends to technology frontier rapidly. In comparison, technological innovation in developing countries is mainly implemented through imitation of "learning by doing" approach (Arrow, 1962; Cohen and Levinthal, 1990; Maclaughlin and Scott, 2010). Over the past two decades, there had been a lot of studies, which specifically focus on the learning process within firms of developing countries, and have identified factors facilitating their learning activities (e.g., Amsden, 1989; Hobday, 1995; Kale and Little, 2007; Kim, 1997; Kim and Lee, 2002; Kim and Seong, 2010; Lall, 1987; Lee and Lim, 2001). They have got agreement on intensity of technological learning efforts that have great impact on latecomer firms' learning.

By formulating a model of firm investment in R&D which contributes to a firm's absorptive capacity, Cohen and Levinthal (1990) argue that lack of investment in an area of expertise early may foreclose the future development of a technical capability in that area. Kim (1997) also analyzes the intensity of learning efforts change during a process of

imitation, which is divided into: duplicative imitation, creative imitation and innovation. Kim and Lee (2002) finish case analyses on technological learning processes of five firms in Korean electronic parts industry, and find these factors facilitating technological learning activities: top management vision, environmental change, external linkage, indigenous development effort, and management system. Lai et al. (2006) denote that long-run growth arises from improvements in absorptive capacity and higher human capital stock. Other scholars reveal that in-house technological efforts (investment in human capital and R&D) are critical for developing original innovations as well as for absorbing technologies transferred from external agencies (e.g., Girma et al., 2009; He and Mu, 2011; Liu and Buck, 2007; Liu and Zou, 2008; Sun and Du, 2010).

However, the learning process of Chinese firms is deferent from that of Korea, as well as other NIEs, and each country has a different history, geography and economic opportunities and problems. The staged model may not meet the needs of China because the current situation in China is obviously different from that in Korea during the 60's and 70's. Chen and Qu (2003) argue that China is experiencing a new form of technological learning. It integrates operational, tactical, and strategic learning, which corresponds to acquisition, assimilation, and improvement respectively. Focusing on the CTV industry, Xie and Wu (2003) find that the most significant difference between learning processes in Chinese firms and those of four dragons is that they rely almost exclusively on export markets, but Chinese firms are mostly focused on local market.

3. Methodology

Since this study is driven by a theoretical research question based on a patchwork of empirical observations, we adopted a multiple-case design, which allows a replication logic, wherein a set of cases is treated as a series of experiments, each serving to confirm or

disconfirm the inferences drawn from the others (Yin, 2009). We selected four China's auto manufacturers that realize innovation from imitation. The four companies fall into two categories: traditional SOEs (FAW, SAIC) with a lot of resource advantages in the competition comparing with emerging private companies (GEELY, BYD AUTO), which have little resources at their starting point, but have achieved great performance on market. Table 1 describes the four companies studied.

Table 1. Description of the four companies studied [a]

Company	Revenue in 2010 (thousand US dollars)[b]	Ownership	Foundation year	Employees in 2010
FAW	45,956,979	SOE	1953	84,191
SAIC	55,372,978	SOE	1955	109,500
GEELY	3,155,815	Private	1997	30,680
BYD AUTO	3,388,961	Private	2003	29,141

[a] Source: China INFOBANK

[b] Exchange rate 1 U.S. dollar against 6.3690 RMB on June 1st, 2012

We collected data on innovation activities of target companies to maximize the validity and reliability of case studies according to the theory stipulated by Yin (2009). The data are mainly from three sources: interviews, archival documents, and direct observations.

A semi-structured form was conducted during the interview process. We interviewed 12 persons of the four case-studied companies from March 2010 to May 2011 respectively, who are executives, technical officers, R&D personnel, senior managers and engineers. The form of those interviews contains the formal face to face interviews, interviews in informal occasion, and a certain number of questionnaires. Each interview was typically 90-120 minutes in length, which not only enriches the research information, but also helps researchers to identify the direction and dimension of relevant research questions by the respondents. We interviewed again 11 persons by telephone and emails to expend on questions in details. After analysis and filtering, nearly 90 percent of interview data were

transformed into the case study database.

It is difficult for researchers to obtain sufficient interview time due to executives are very busy. It is necessary to use other open information for enriching data sources and a multi-dimensional research, such as a combination of media coverage about key persons of relevant enterprises. With the limitation of the researchers' contact, it is feasible to use public interviews of related officer in target enterprises as a way of information supplement. Gallager and Parker (2002) and Lynn (1998) have used this method to carry out academic research. Therefore, we collected a number of CEOs' interviews in related websites, newspapers and magazine as supplement data. .

In addition, we collected 40 internal archival documents from four case sites. These documents include year reports, corporate developing strategies, R&D plan, internal memo, CEO's reports, and historical sales volume and avenue materials. We also collected more than 80 public documents pertaining to the four case firms, including press releases, statistical yearbooks, industrial research reports, and journal articles. The public data mainly come from China Financial Database (China INFOBANK), State Intellectual Property Office of China (SIPO), and SOHU Auto Database. These documents are very useful and helpful for us to examine and retrospect the interviews to remove some bias.

Only interviews cannot obtain sufficient field information. From January 2010 to January 2012, we attended and recorded eight innovation-related meetings of the four case firms, to observe strategy, management, process, and innovation. We got 12 events for the research and transformed them into the case study database.

By choosing these four auto firms in China, we carried out a comparative research horizontally, and tried to explain the differences between their technological innovation processes at the same time. This paper will evaluate technological innovation from imitation by (1) their technological innovation developing stages; (2) technological learning strategies,

basically concerning the intensity of technological efforts, such as R&D input and talent strategy; and (3) consequently, the innovation achievements according to the data of patents and self-brand sales revenue per capita.

4. Findings

4.1. Technological innovation developing stages of China's auto firms

Herein we try to summarize the technological innovation process of China's auto firms by dividing them into two categories including SOEs and private enterprises in Table 2: for SOEs, they start from duplicative imitation, and shift to accumulate production capabilities through JVs, but not get great progress during the middle developing stage as those firms in NIEs, and finally decide to develop self-brand cars; for private companies, they try to acquire production and product development capabilities through imitation and continuous improvement from the starting point, and always put independent innovation in mind which shortens their assimilation process quite a lot, especially in current open environment.

Table 2. Technological innovation developing stages of four Chinese auto firms

Categories	Companies	Technological innovation developing stages		
		Stage one	Stage two	Stage three
SOEs	FAW; SAIC	duplicative imitation	OEM and technology acquisition through JVs	ODM, OBM and independent innovation
Private	GEELY; BYD AUTO	duplicative imitation on mature technology	creative imitation on engineering and design	independent innovation on high-end product and emerging technology

4.2.Similarities and differences of technological innovation mode between China and other NIEs

Regarding similarities, as mentioned above, technological innovation development mode occurred in China's auto industry is inherently the same with that of other NIEs' (Hobday, 1994, 1995; Kim, 1980, 1997). First, technological innovation tends to develop in sequence and is more or less the reverse of conventional A-U model of technology evolution in advanced countries. In this respect we are just confirming patterns found in other NIEs. As four auto firms cases show, the focus of firms' technological catching-up from imitation to innovation includes learning the art of production, learning primary product development skills, and then building innovation capabilities. Technological innovation is not an instantaneous event but a time-based process involving several stages, and generally includes acquiring, assimilating, adapting and improving existing or imported technology, and/or creating new technology. All of these processes require targeted continuing technological efforts (Lall, 1992).

But here we also have differences in technological innovation mode between China's auto firms and the NIEs' firms. From main stream point of view on latecomer firms' technological catching-up process, substantial innovation occurs via the absorption of foreign technology from abroad. Hobday (1995) gives that technology stages in firm-level changing in terms of interacting technology and market transition from OEM, to ODM and OBM, as well as Kim's model (1980, 1997) of acquisition, assimilation and improvement. In summary, these firms of NIEs, such as Korea, normally begin with acquiring technology from advanced countries through patterns as setting up JVs and purchase of foreign equipment. With regard to SOEs in China, they basically follow the stages from acquiring of foreign technology to independent innovation themselves based on assimilation, which is noted as Kim's (1980, 1997) and Hobday's (1995) catching-up models in NIEs approximately. However, this mode seems not fit the technological innovation process of China's private auto companies such as GEELY and BYD AUTO which neither have gone through JVs to assemble foreign standardized

products, produce differentiated products, improve products and apply these abilities to different product lines; nor started from OEM, then to ODM and OBM. They have shown two features at least: First, these private auto firms in China accumulate fundamental production and product development capabilities by imitating mature technology domestically, for instance, GEELY's imitation process on Red Flag cars of FAW and Xiali cars of TAG, BYD AUTO's reverse engineering on the benchmark vehicles bought from market. Second, related prior knowledge and technology accumulation such as GEELY'S motorcycle or BYD AUTO's electronic products along with approaches on learning also help them to assimilate mature technology more quickly and deeply, which also can be seen as possessing stronger absorptive capacity during imitation stage. For example, before entering auto industry, GEELY is a famous motorcycle producer in China, and BYD AUTO is a leading company in battery and electronic parts in the world with the acquisition of Qinchuan Automobile, and Beijing Mold Company at an early stage.

Based on these two characteristics of private auto companies in China during their technological catching-up process, we can conclude that technological innovation mode of China's firms is different from that of other NIEs', especially for auto companies. There is no single innovation mode within China's auto industry, but a hybrid mode to implement technological innovation, which stands for these companies, who have rushed into the field at different time with diverse backgrounds, do not follow the same development process but present a mixed and various mode of technological innovation in China's auto industry.

4.3.Technological efforts and achievements of China's auto firms

Researchers argue that technological effort is one of the key factors affecting the absorptive capacity of latecomer firms during a learning process to catch up (Cohen and Levinthal, 1990; Girma, 2005; Newey and Shulman, 2004; Sen and Rubenstein, 1990).

Absorptive capacity refers to the company's knowledge base and in-house efforts (Kim, 1997). Furthermore, empirical evidence has suggested that a higher level of R&D effort improves a firm's ability to convert external technical knowledge into innovation activities (Mowery et al., 1996; Song et al., 2005; Tsai and Wang, 2008). Thus we collected data of these four auto firms, to check their intensity of technological effort, which normally measured by R&D input, R&D intensity and talents strategy.

Although SOEs have more instinctive advantages in capitals and getting support from the government, their investment in R&D is much lower than private auto companies, both on R&D input and its intensity. From the recent five years average of R&D intensity, FAW only gets 1.5%, SAIC with 2.6%, while GEELY reaches 6.7%, BYD AUTO with 3.4%. These two private companies are both above average level among Chinese auto firms, showed in Table 3 and Table 4. This result can partly explain that the private auto companies use fewer years to reach technological innovation without setting up JVs to acquire technology from MNEs as SOEs.

Table 3. The R&D input of four firms from 2006 to 2010 (billion RMB) [a]

Year	FAW	SAIC	GEELY	BYD AUTO
2006	2.5	4.9	0.6	0.4
2007	2.4	6.3	1.0	0.7
2008	2.4	7.5	1.0	1.2
2009	3.6	7.9	1.0	1.3
2010	4.5	4.7	3.2	1.4
average	3.1	6.2	1.4	1.0

[a] Source: China INFOBANK

Table 4. The R&D intensity of four firms from 2006 to 2010 (%) [a]

Year	FAW	SAIC	GEELY	BYD AUTO
2006	1.7	2.8	6.6	3.1
2007	1.3	3.0	8.3	3.3

2008	1.1	3.3	7.7	4.3
2009	1.7	2.3	6.2	3.3
2010	1.6	1.3	4.7	3.0
average	1.5	2.6	6.7	3.4

[a] Source: China INFOBANK

Another important reason is the different talent strategies in their R&D departments. According to open data of four firms in 2010, the R&D human capital intensity of private companies is much higher than that of SOEs; especially, R&D human capital occupies 17.2% of total employees in BYD AUTO, showed in Table 5.

Table 5. The R&D human capital of four firms in 2010 [a]

	FAW	SAIC	GEELY	BYD AUTO
R&D human capital	2,777	1,932	2,381	5,000
Total human capital	84,191	109,500	30,680	29,109
R&D human capital intensity (%)	3.3	1.8	7.8	17.2

[a] Source: China INFOBANK

Moreover, the private auto companies not only hire engineers directly from the academy, but also hunt experienced specialists all around the industry in the world, which can shorten their assimilation period greatly with their "know-how" and tacit knowledge. Although GEELY Automobile Research Institute was set up later than FAW's and SAIC's R&D centers, it has built a R&D team of 2,381 persons, including senior technical experts engaging in multi-year R&D work with more extensive automotive industry background from the well-known research institutes or auto companies. Several of them are showed in Table 6.

Table 6. Several experts hunted by GEELY from outside

Experts	Before or Now	Now	Niche	Joining Time
Guo, Konghui	Academician of Chinese Academy of Engineering	Technology Consultant of GEELY Group, Project Leader of GEELY hybrid	Automotive Technology	2005

		cars		
Hua, Fulin	Deputy Chief Engineer of FAW Automobile Research Institute	Chief Engineer of GEELY Automobile	Chassis R&D	2004
Jiang, Shubin	Vice Deputy of FAW Technology Center	General Manager of GEELY Ningbo Co., Ltd.,	Production Management	2002
Pan, Yanlong	Chief Engineer and Director of Engineering Center of Nanjing Fiat	Chief Engineer and Dean of GEELY Auto Research Institute	R&D System Building	2002
Shen, Fengxie	Chairman of Korean Automotive Engineers Society, Director of Korean Daewoo R&D Center, Vice President of Daewoo International	Vice President of GEELY Group	Vehicle R&D	2004
Wen, Bandchun	Academician of Chinese Academy of Science	President of Beijing GEELY University	Mechanical Technology	
Xu, Binkuan	Chief Engineer of Tianjin Gear Factory	General Manager of GEELY Transmission Co., Ltd., Director of GEELY Transmission Institute	Transmission Development	2002
Xu, Gang	Chief Accountant of Zhejiang Province Tax Bureau	CEO	Corporate Governance, Financial Management	2002
Yang, Jianzhong	Deputy Chief Engineer of FAW Technology Center	Chief Engineer	Engine Design	2002
Yin, Daqing	Financial executives of DuPont, JAIC and Huachen Auto Group	Vice President and CFO	Group Management	2004
Zhao, Fuquan	Director of Chrysler Technology Center and Vice President of Huachen Auto Group	Vice President and Director of GEELY Auto Research Institute	Vehicle R&D	2006

Zhao, Tieliang	Engineer of Shenyang Jinbei Automotive Industry Co., Ltd. (JAIC)	Chief Engineer of GEELY Engine Research Institute	Engine Development	2003
Zhi, Bainian	Chief Engineer and Vice Factory Director of FAW Car, Senior Manager of FAW- VW Product Engineering department	Executive Vice-President of GEELY Auto Research Institute	Automotive Electronics	2002

By comparative analysis on R&D input and talent strategies of these two categories of auto firms in China, we figure that technology acquisition does not necessarily lead to acquisition of technological innovation. If firms don't translate the acquired technology into technology assets through its own R&D activities, and then technology acquisition is meaningless. Duplicative imitation is no substitutes for R&D activity itself correspondingly, the actual development process-design, experimenting, and testing must be conducted completely, and these series of R&D activities need financial investment and R&D human capital input. The previous analysis can also be seen in this regard that differences of technological efforts during learning process may result in different technological innovation developing stages and achievements.

In this study, technological innovation achievements are evaluated by the number of patents obtained in China, as well as sales revenue of self-brand products in 2011.

With respect to patents, by the end of 2011, the total patents obtained by FAW is 2,627, more than half of the patents concentrate in the utility category, while SAIC only obtains 593 patents because most of their technologies are acquired from outside sources. From the perspective of technological innovation, invention patent stands for higher degree of innovation; utility patent reflects a higher degree of improvement on existing technologies. And the duration of patent right for invention is twenty years; the duration of utility patents

and design patents is only ten years. In terms of the effectiveness of intellectual property protection, invention patent has a higher value. This "quality and quantity " gap also reflects in the private car companies, such as BYD AUTO has obtained 7,708 patents by the end of 2011, a dominant position in China's auto industry, but 49% of them are utility patents, which indicates a distance to MNEs with strong technological innovation capabilities. And GEELY has also gained a large number of 3,567 patents, while 75% of which belong to utility type, showed in Table 7.

Table 7. The obtained patents of four firms by the end of 2011 [a]

	FAW	SAIC	GEELY	BYD AUTO
Invention patent	550	105	367	3,740
Utility patent	1,502	229	2,709	3,162
Appearance design patent	575	259	491	806
Total	2,627	593	3,567	7,708

[a] Source: SIPO

In terms of self-brand sales revenue, Table 8 shows that the private auto firms have better performance than SOEs, especially from the sales revenue per capita. In 2011, BYD AUTO gets 1,129 thousand RMB per capita from self-brand sales, and GEELY gets 961 thousand RMB on this index, which are much higher than FAW and SAIC, the self-brand sales per capita of which are only 163 and 195 thousand RMB. These results show that the innovation achievement of private auto companies is stronger than that of SOEs in China.

Table 8. The self-brand sales volume and revenue of four firms in 2011 [a]

	FAW	SAIC	GEELY	BYD AUTO
Self-Brand Sales Volume (unit: thousand units)	113	160	456	454
Self-Brand Sales Revenue (unit: billion RMB)	13.8	21.4	29.5	32.9
Self-Brand Sales Revenue per capita	163	195	961	1,129

(unit: thousand RMB)

[a] Source: SOHU Auto Database

5. Conclusions

Past research on technological innovation has showed that it is possible for latecomer firms to catch up from imitation through a technological learning process. This paper proceeds by examining technological innovation process of indigenous auto firms in China, trying to explain how auto firms realize technological innovation by imitation, as well as the differences between China's auto companies and other NIEs' from imitation to innovation.

Through comparative analysis on four auto companies in China, this study finds that: first, although technological innovation process of auto firms in China travels along from imitation to innovation overall, it not quite follows the catching-up mode happened in other NIEs, which reveals a hybrid mode combining traditional Hobday's (1995) and Kim's (1980, 1997) models. For SOEs, they basically follow the stages from acquisition of foreign technology and setting up JVs to innovation, but finally realize that technological innovation must be endogenous, and must be obtained through their own organized learning and products development. As for China's private companies, whose innovation paths neither have proceeded through JVs nor started from OEM, to ODM and OBM, they accumulate fundamental production and product development capabilities by imitating domestic mature technology. They attempt to master the modern art of vehicles assembly and primary product development procedure at the very start through duplicative imitation and continuous improvement, and build self-brand cars with long-term practice of relentless independent R&D to accumulate technological innovation capabilities more rapidly.

Second, there exist two main differences between these two categories auto firms: 1) the R&D intensity and R&D human capital intensity of SOEs are much lower than that of private firms; 2) Consequently, their achievements on technological innovation has a great gap:

performance on patents obtained in China and self-brand sales revenue, especially on per capita index, private auto firms create more sales revenue with less employees.

Third, learning is an important factor in enabling firms to achieve technological catching-up. Regarding the effects of technological learning, given the huge market in China, it is possible to access foreign knowledge in an open environment. However, indigenous firms must enhance their technological efforts to assimilate acquired technologies, so as to improve their sustainable technological innovation capabilities. Especially for auto firms, from vehicle design, key components manufacturing, to system integration, which involves complicated technical categories to control the content and relationship of all aspects, they should depend on the accumulation of in-house technological efforts.

Our findings also imply that China's auto firms can achieve technological innovation through learning starting from imitation. Both SOEs and private auto companies should utilize different kinds of ways to acquire technology from outside in this open environment combining tremendous technological efforts, to improve their technological innovation capabilities constantly. And the patterns presented in this paper are not necessarily singular to China, on account of a changing environment distinguished from four East Asian tigers' catching-up era, namely the technology leaders' growing reluctance to transfer of technology, the emergence of various standardization groups, the shortening of technology/product life cycles and the phenomena of technology fusion. Concerning about similar international situation, latecomer firms of other catching-up countries as India, Brazil and Russia may emulate China's private auto firms' mode someway and learn lessons from some mistakes committed by China's auto firms, not to repeat them.

As this paper is based on four cases, the generalization of research results is limited, and still needs supplements and corrections when considering more China's auto enterprises with more deep investigations. Thus, further research and investigation is necessary to validate the

proposed findings in this paper. In addition, similar research needs to be conducted in other developing countries and other industries to formulate more general propositions.

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