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The effects of forward and reverse engineering on firm innovation performance in the stages of technology catch-up: An empirical study of China

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ABSTRACT

Due to the lack of novel technology, most emerging economies are adopting a technology catch-up strategy by first imitating and then innovating, which leads to a complex but important interaction between technology imitation and indigenous R&D activity, both of which play important roles in the innovation production process of emerging economies. Accordingly, this study proposes a new analytical framework that takes into account both forward engineering, mainly characterized by R&D novelty, and reverse engineering, mainly characterized by technology imitation. Based on this framework, this study offers an in-depth analysis of Chinese high-tech firms. The empirical results show that reverse engineering positively interacts with forward engineering; Firms with input in reverse engineering have more innovation output and a greater level of innovation commercialization than firms without input in reverse engineering. Forward engineering has a greater direct contribution to innovation output and innovation commercialization than reverse engineering. By comparison, the reverse engineering functions on innovation output mainly through indirect effect, which intensifies the role of forward engineering by providing the knowledge base for novel R&D activity. However, the ethicality and legitimacy of intellectual property behind reverse engineering frequently lead to international prosecutions, which may be the main reason that reverse engineering has an insignificant effect in the overseas market. Our study indicates that governments should initiate technological policy for technology development, and firm managers should improve indigenous innovation capacity.

1. Introduction

Most emerging economies, e.g., China, regard the development of science and technology as the key engine for catching up with industrialized economies (Bin, 2008; Ning, 2009; Liu et al., 2011; Wang et al., 2014). In the open innovation paradigm, technology can come from inside or outside the company and can go to market from inside or outside the company as well (Chesbrough, 2006), which provides an opportunity for emerging economies to access overseas technologies. Because of the industry-wide technology diffusion in the context of open innovation, firms usually need to choose between imitation and innovation (Semadeni and Anderson, 2010; Cappelli et al., 2014). Since firms from emerging economies acquire the capability to create new products and processes from industrialized economies, they eventually make the leap from imitation to innovation, a technology catch-up strategy that is carried out by many emerging economies.

As Kim and Nelson (2000) have noted, it is important to adopt a broader view of R&D in emerging economies, which is mostly in the stages of technology catch-up. R&D in emerging economies involves both original innovation and imitation, with the latter even playing a more important role, particularly in the early stages of economic and technological development (Hu and Jefferson, 2004). Imitations are usually carried out through "reverse engineering", which adopts and adapts existing and often mature technologies by extracting know-how or knowledge from autopsies of the final products (Samuelson and Scotchmer, 2002; Eun et al., 2006). Reverse engineering sometimes makes improvements based on the extant technologies (Mukoyama, 2003), which earns little economic rent in developed economy markets. However, they can be very useful to firms in emerging economies seeking to capture a share of the international value chain, which has been important to the success of Asia's industrialized economies (Hu and Jefferson, 2004), e.g., Japan, Korea and Taiwan are all "creative imitators" with a three-step process of knowledge acquisition, assimilation and improvement (Kim, 1997; Katz, 1998).

Achieving understanding and knowledge assimilation forms the basis for improving the knowledge gained. Many studies in the literatures have noted that the assimilation of outside technologies, i.e. the technologies embodied in (imported) final products in the case of reverse engineering, is heavily dependent upon the development of indigenous innovation capability (Tolentino, 1993; Kim, 1997; Young and

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Lan, 1997; Chen and Chen, 2004; Morgan, 2004; Eun et al., 2006), which devises the basis for "forward engineering" that moves from high-level abstractions and logical, implementation-independent designs to the physical implementation or commercial utilization (Chikofsky and Cross, 1990; Lu, 2000). Many emerging economies are working hard at this, as observed in China's huge investment in the basic R&D of aircraft and automobile engine and India's success in the software industry. However, without the inflows of technology and reverse engineering, emerging economies are less likely to have a higher growth rate because they must rely on purely domestic R&D, which will be less efficient and more costly than R&D in the industrialized economies given their longer experience and larger R&D efforts (Pack and Saggi, 1997). Therefore, both reverse and forward engineering play important roles in emerging economies' innovation production processes.

The ethicality and legitimacy of reverse engineering carried out by China is frequently criticized by industrialized economies, because this usually leads to imitations and even counterfeits, which hurt the overseas novel inventors. Available statistics on copyright piracy indicate that losses from all types of copyright piracy in China in 2005 amounted to 2.5 billion USD (Dimitrov, 2009). However, to facilitate the catch-up strategy and narrow the technology gap, China as the technology followers usually do not strictly enforce the intellectual property right (IPR), for example, despite legal provisions that ban and punish infringement, pirates remain common in China, because GDP indicators urge the authorities not to attempt strict enforcement of the law (Minagawa et al., 2007; Dimitrov, 2009). With a relatively low level of legal constraint, firms are more likely to invest in reverse engineering. However, products from China are usually banned in the international trade due to intellectual property infringements. Although the defect of legislation, administration and enforcement indulges technology infringement in the domestic market (Zhang et al., 2014), the prosecution risk in the overseas market compels China to reduce imitation and increase innovation, which makes it difficult to balance between reverse and forward engineering.

The innovation production process is more complex in emerging economies, where reverse and forward engineering usually interact with and weigh against each other (Pack and Saggi, 1997). Much research in the literature has offered in-depth analysis of technology acquisition, indigenous R&D and their correlations, e.g., Cohen and Levinthal (1989); Basant and Brian (1996); Blumenthal (1979); Deolalikar and Evenson (1989); Katrak (1989); Braga and Willmore (1991); Siddarthan (1992); Bertschek (1995); Cheung and Lin (2004) and Zhao (1995); Zhou (2006). However, there is still a lack empirical studies with sufficient data that attempt to differentiate reverse from forward engineering, a distinction which requires further examination. Additionally, because R&D typically includes many interactions and technologies are produced in a systematic process (Guan and Chen, 2012), it is necessary to take a broader view by differentiating the role of forward from reverse engineering in the innovation production process framework. Rothwell (1994); Rogers (1995); Geisler (1995); Brown and Svenson (1998); Bernstein and Singh (2006); Galanakis (2006); Cantisani (2006) presented the theoretical explorations of the process-oriented innovation activities. Based on the aforementioned theories, Chen and Guan (2011); Guan and Chen (2010, 2012) proposed analytical frameworks and an empirical study of the innovation production process that mainly focuses on only the forward engineering. However, technology acquisition and imitation, mainly through reverse engineering, are not taken into account. Because reverse engineering plays an important role in the R&D activity in emerging economies, the innovation production process is quite different from that of industrialized economies. Wang et al. (2014) proposed an innovation framework that mainly focuses on the effect of R&D novelty and openness, while ignoring their interactions that represent a potentially important innovation activity. In addition, their framework also did not take a systematic view of the innovation production process, which also includes the impact of innovation output on innovation commercialization, as is proposed by Chen and Guan (2011). Therefore, an essentially new systematic innovation production process applicable to emerging economies should be proposed.

Because reverse engineering from products and equipment to documents is rarely reported by local partners or local firms (Lan and Young, 1996), it may be difficult to identify reverse engineering input and to what extent it contributes to innovation performance. To obtain knowledge about the input–output efficiency of high-tech firms, the MOST (Ministry of Science and Technology of China) initiated a five year survey. One of the key items is the allocation of R&D expenditures, which includes the technology acquisition fee and the cost of reverse engineering activities.

With the new innovation production framework and the data from MOST, we contribute to extant literature from the following three perspectives: first, we re-map the innovation production process by taking into account the interactions between reverse and forward engineering, thereby providing a new analytical framework for the open innovation theory. Second, we examine which type of R&D input, either forward or reverse engineering, plays a major role in firms' innovation production process in China in the stages of technology catch-up, which is not clearly examined by extant studies. Third, for most emerging economies, such as China, domestic and overseas markets are essentially different in terms of the IPR enforcement. Products that stem from reverse engineering are frequently banned by international intellectual laws. However, prosecuting counterfeit products in emerging markets is difficult, because the IPR is legally not well protected (Minagawa et al., 2007). Reverse engineering may thereby function well in the domestic market, whereas it plays an insignificant or even negative role in the overseas market, as study explores.

The remaining parts of this study are organized as follows: Section 2 presents the theoretical framework and hypothesis, Section 3 presents the data and method, Section 4 presents the empirical result, Section 5 discusses and Section 6 concludes.

2. Theoretical framework and hypothesis

2.1. Theoretical framework

In terms of antecedents and consequences, a complete innovation production process starts from idea generation and ends with innovation commercialization (Bernstein and Singh, 2006; Roper et al., 2008; Guan and Chen, 2010). Idea generation derives from previously accumulated knowledge stock (Romer, 1990; Chen and Guan, 2011). Thereafter, a series of consequent strategic/planning activities (e.g., investigating, comparing and goal setting) are necessary for further innovation investment along with resource allocations supporting the consequent R&D activities as well as relevant technological import and absorption activities (Chen and Guan, 2011). After a process of researching, developing and testing, the intermediate technological innovation products are produced. The complete innovation production process is finally accomplished in the economic sense, when the first commercial transaction of R&D outputs is produced in the market (Freeman and Soete, 1997). Accordingly, Chen and Guan (2011) proposed an innovation production framework that consists of four functionally distinct but interdependent sub-processes: idea generation originating from technology accumulation, innovation investment mainly in forward engineering and R&D personnel that produce innovation output, and innovation commercialization (see Fig. 1). Idea generation and innovation investment function on both innovation output and innovation commercialization, which leads to many correlations and interactions in Fig. 1.

Because the framework in Fig. 1 does not further breakdown R&D input, it may only be a general description of the innovation production process. After adding the construct of reverse engineering (see Fig. 2), the interactions between forward and reverse engineering lead to a new framework that is more applicable to describing the innovation production process in the phases of technology catch-up. As shown in Fig. 2, the reverse engineering functions on both innovation output