The effect of R&D novelty and openness decision on firms’ catch-up performance: Empirical evidence from China

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\textbf{Abstract}

This paper explores the strategic dimensions of R&D decisions toward novelty and openness in explaining the performance of latecomer firms in a developing economy. A structural equation model of R&D decision-making is formulated using survey data from 279 Chinese firms. The dimension of R&D novelty is defined as the degree of technological newness found in firms’ R&D projects, while R&D openness describes the degree to which technologies are acquired from external sources. Our results indicate that firms’ R&D decisions regarding novelty and openness are associated with demand opportunities, market competition, technological capability, and external networks. Greater R&D novelty contributes positively to innovative output but does not affect sales growth. Greater R&D openness contributes positively to sales growth but negatively to innovative output.

1. Introduction

Chinese leaders have long placed the development of science and technology at the center of China’s modernization plan, regarding it as the key engine for catching up with advanced industrialized countries (Bin, 2008; Liu et al., 2011; Ning, 2009). Over the last two decades, China has been continuously making substantial investments in R&D. This spending reached a record high of 162 billion US dollars in 2012, accounting for 1.97 percent of China’s GDP and making it the second most R&D-intensive country in the world since 2009 (ChinaDaily, 2013; OECD, 2012). Such a huge R&D effort was also made in the hope of transitioning the country’s economy from being labor-intensive and export-led to a more sustainable innovation-driven growth model by 2020, as announced in China’s 12th Five Year Plan for Science and Technology Development.

In this economic transitional period, Chinese firms, similar to their East Asian newly industrialized economy (NIE) counterparts in the peak of their catch-up period, face a “strategic dilemma”. This dilemma is whether they should try to become innovation leaders, relying on in-house R&D, or continue their low-cost, imitation-based competitive strategies (Hobday et al., 2004; Xiao et al., 2013). This is particularly relevant for some of China’s largest firms (e.g., Huawei, Lenovo, and PetroChina) and is increasingly important for many others that are approaching multinational stages. Given China’s substantial investment in technology and innovation, it is important to understand how firms are making their R&D decisions to catch up and reduce the technological gap with the industrial leaders.

Previous research has well documented the processes of technological capability building by NIE latecomers. One view rooted in the product life-cycle theory is that latecomers improve their technological capability following the technological trajectory of the developed country firms by assimilating and adapting relatively obsolete technology (Kim, 1997; Utterback and Abernathy, 1975; Vernon, 1966). Latecomers should initially focus on developing production capability through licensing or joint ventures and then move on to building independent technological capability in stages (Kim, 1980, 1997). An alternative view derived from the Perez and Soete’s (1988) leapfrogging thesis suggests, on the contrary, that the constraints on an innovation pattern are lifted by technological paradigm shifts. This type of ‘window of opportunity’ allows latecomers to catch up, as all industry players are new to the emerging paradigm. Latecomers can omit some parts of the trajectory or even forge novel pathways, bypassing older technology
to catch up with advanced countries (Hobday et al., 2004; Lee and Lim, 2001; Mu and Lee, 2005; Park and Lee, 2006; Perez and Soete, 1988; Xiao et al., 2013).

Latecomer transition, however, is not a simple dichotomy between catch-up and leadership strategy, as technological development and innovation are not mutually exclusive options (Hobday et al., 2004). R&D investment is not a result of catching up but an important input to enable it (Hobday et al., 2004; Mu and Lee, 2005). Considerable R&D is required for firms to achieve radical innovation and alter the patterns of competition. All NIEs have spent a substantial amount on R&D during their catch-up process (Gill et al., 2007; OECD, 2012). However, relatively little is known about the strategic dimensions of latecomer firms’ R&D decisions and the consequential innovation performance in their catch-up process.

To this end, this paper deconstructs R&D behaviors along two strategic dimensions to answer this question: R&D novelty, which is the extent to which firms employ technological newness in products or production processes through knowledge exploration and exploitation, and R&D openness, which is related to the degree to which firms’ knowledge sourcing strategy is through internalization or externalization (see Section 2 for details). Because R&D behaviors are constrained by the specific conditions of the technological regime, a theoretical framework is built to link antecedents, R&D decisions, and consequent outcomes to explain latecomers’ technological catch-up performance. We use a structural equation model based on a survey of Chinese firms.

This study contributes to theory development and has practical implications for managers and policy-makers in China as well as providing a useful reference for other developing countries that are promoting their technological development. Regarding theory development, this paper reanalyzes several common R&D concepts and attempts to integrate R&D decisions into a comprehensive and consistent technological catch-up framework. Regarding practical implications, the results of the structural equation model provide guidance on how to implement R&D resource allocation to balance novelty and openness, which, in turn, helps to address the challenge of optimizing the balance between imitation and innovation. Moreover, this quantitative study of R&D decision-making complements the many qualitative studies in the field of catch-up research.

The remainder of this paper is organized as follows. We develop a conceptual model and our hypotheses in Section 2. Section 3 describes the research methodology and measurements, while Section 4 contains an analysis of the structural equation model. In Section 5, we present the results and discuss the empirical findings. Section 6 summarizes the key findings, outlines the managerial implications, and discusses the limitations of our research and directions for future research.

2. Theoretical background and hypothesis development

2.1. The novelty and openness dimensions of R&D decisions

The central concern of the literature on adaptive search behaviors is the relationship between the exploration of new vs. exploitation of existing technological capabilities in ensuring firms’ competitiveness and the association of different types of learning and innovation (March, 1991). Exploitation is described as local searches that locally address ‘problems’ using knowledge that is closely related to the pre-existing knowledge base of a firm (Ahuja and Morris Lampert, 2001; Katila and Ahuja, 2002). Exploration is characterized as exploratory or distant searches that involve a deliberate effort to depart from present organizational routines and knowledge bases (Katila and Ahuja, 2002; March, 1991; Rosenkopf and Almeida, 2003; Stuart and Podolny, 1996). Due to the path-dependent nature of technological innovation, firms need to combine these two search activities. Exploration without exploitation is likely to suffer from the high costs of experimentation and high rates of failure because of the inherent risks and uncertainties. Conversely, exploitation without exploration is likely to be trapped in suboptimal equilibriums due to core rigidities or competency traps (Gilsing and Duysters, 2008; Gupta et al., 2006; March, 1991; Nooteboom, 2000; Rosenkopf and Almeida, 2003; Yamakawa et al., 2011). Both activities are essential but compete for the same resources. As a result, achieving an optimum balance between the two to combine internal and external knowledge is a primary requirement for making R&D decisions on search behaviors (Bauer and Leker, 2013; Katila and Ahuja, 2002; Rivkin and Siggelkow, 2007). More importantly, the exploitation and exploration framework indicates that the key difference between the two is the degree to which search behaviors involve the development of new knowledge and sources of such knowledge creation.

Previous research has noted that catch-up firms’ R&D behaviors are dependent on different technological regimes (Cho and Lee, 2003; Malerba and Orsenigo, 1993; Park and Lee, 2006). There is also considerably less clarity on how latecomer firms make use of R&D resources (Gupta et al., 2006; Kale and Wield, 2008). To arrive at an integrative view of latecomers’ R&D decisions on search behaviors, we build on this exploitation and exploration framework and propose two strategic dimensions, R&D novelty and R&D openness. The first novelty dimension is related to the development of new knowledge, as firms often need to decide the extent of newness in their search behaviors, i.e., based on pre-existing knowledge (exploitation) or moving away from their current knowledge base (exploration). R&D novelty can therefore be defined as the extent of technological newness found in R&D projects, e.g., significantly new products or improved production processes (Bauer and Leker, 2013; Hult et al., 2004; Luecke and Katz, 2003; Rhee et al., 2010). Imitation can be a creative process, but it is not completely distinct from innovation (Dosi, 1988). In cases of high absorption costs, imitation may even be more economically expensive than the original innovation (Cohen and Levinthal, 1990). Furthermore, firms might need to acquire technology far from their existing knowledge base to avoid the familiarity trap and break existing technological paradigms (Ahuja and Morris Lampert, 2001; Gilsing and Duysters, 2008). The challenge for latecomers is more about increasing the novelty of innovation rather than whether the firms innovate. The choice over the extent to which search behaviors should be new is a trade-off in budget allocation between innovation and imitation (Nelson and Winter, 1982).

The other strategic dimension, R&D openness, is related to the sources of knowledge creation. Firms need to choose the extent of openness these exploitation and exploration search behaviors should incorporate, i.e., relying mainly on internal R&D efforts (internalization) or searching for external technology (externalization), to explore and exploit technology innovation. R&D openness can be seen as the extent to which technologies are acquired from external sources. These strategies cover a mixture of in-house R&D, strategic alliances, licensing of technologies, and other approaches. The transaction cost perspective has emphasized the costs related to these external sourcing options, such as organizational coordination, partner selection, risks of imitation, and knowledge leakage (Robinson and Gatignon, 1998; Steensma and Corley, 2001).

The knowledge-centered perspective in this paper is based on and focuses instead on boundary-spanning exploration choices (Rosenkopf and Nerkar, 2001). To escape from the negative effects of local searches and succeed in following sudden and unanticipated changes in the environment, exploratory search behaviors have to span some boundaries, be they organizational
or technological (Rosenkopf and Almeida, 2003). Previous research has shown that spanning organizational boundaries rather than technological boundaries plays an important role in improving the innovation performance of a firm (Lavie and Rosenkopf, 2006). Similarly, researchers have found a positive effect of alliances on shifts in technological focus (Stuart and Podolny, 1996) and demonstrated the role of openness in explaining innovation performance (Chesbrough, 2003; Laursen and Salter, 2006; Lichtenhaler, 2008).

External sources contribute a great deal to technological progress through informal processes of diffusion, externalities that are internalized, and the adoption of innovations developed by others (Berchicci, 2013; Cassiman and Veugelers, 2002). However, it is not an all-or-nothing substitute for in-house searches, which are still the dominant organizational form for technological searches (Dosi, 1988; Hagedoorn and Wang, 2012; Lichtenhaler, 2008; Mu and Lee, 2005). Some researchers have found that greater internal R&D investment with lower R&D outsourcing contributes more to firms’ innovation performance. The benefit of external R&D is moderated by internal R&D investment in the context of NIEs (Berchicci, 2013; Fan, 2006; Hagedoorn and Wang, 2012; Tsai and Wang, 2008, 2009). Firms’ technology sourcing strategy, therefore, is not a simple dichotomy between internalization and externalization, involving a mixed degree of openness depending on the project (Grimpe and Kaiser, 2010; Praest Knudsen and Bøtter Mortensen, 2011; Trott and Hartmann, 2009).

### 2.2. Dimensions of R&D decisions toward novelty and openness within catch-up strategy

R&D search behavior is induced by technological opportunities. Opportunities in the form of knowledge sources are characterized by complementarities between sources that are internal and external to the organization. Together with opportunity conditions, three other factors (appropriability conditions, degrees of externalities that are internalized, and the adoption of innovations developed by others) are part of the technological regimes that define patterns of R&D behaviors (Cohen and Levinthal, 1990; Malerba, 2002; Malerba and Orsenigo, 1993).

Previous research attempting to explain the technological catch-up of NIEs has demonstrated the relevance and influence of technological regimes in the catch-up process (Lee and Lim, 2001; Lee et al., 2005; Mu and Lee, 2005; Park and Lee, 2006; Xiao et al., 2013). However, the conditions of technological regimes are more effective in explaining differences across sectors than intra-sectoral variances. At the firm level, according to a critical review by Dosi (1988), two points should be considered to find the crucial dimensions for firms’ R&D decisions. First, the level of cumulativeness and characteristics of the knowledge base as well as partial appropriability, which reflects the permanent existence of asymmetries among firms. As (Rosenkopf and Almeida, 2003; Rosenkopf and Nerkar, 2001) have suggested, local searches help accumulate ‘first-order competence’, i.e., the development of unique technological capabilities. Therefore, firms can be ranked in terms of technological capability as better or worse according to their distance from the technological frontier. Additionally, opportunities are influenced by the degree to which they can draw from the knowledge base and technological advances made by suppliers and customers. Accordingly, sourcing external knowledge is complementary to internal technological capabilities for exploiting opportunities (Cassiman and Veugelers, 2005). Furthermore, in addition to these two technology-related factors (i.e., technological capability and external networks of knowledge), market-related factors, such as demand and competition, may influence R&D (Dosi, 1988, 1997). To explain latecomers’ catch-up innovation performance at the firm level in this study, we focus on four factors that have a direct impact on the R&D decision-making process: technological capability, external networks of knowledge, demand, and competition.

Demand opportunity reflects the potential for market demand to induce technological innovation. When market demand is diversified and dominant design does not occur, there will be more demand opportunity for latecomers to catch up with less R&D investment (Breschi et al., 2000; Malerba, 2007; Murmann and Frenken, 2006). One approach is the use of technological improvement based on imitation to satisfy markets with less demanding customers at a price discount (Murmann and Frenken, 2006). Another is OEM based on importing mature technology to acquire low-cost profits from exportation (Hobday, 1995). Otherwise, latecomers need to invest more to develop new technological functions based on applied and basic research to avoid a price war under conditions characterized by less variety of demand, high performance preferences, and difficulties in exporting to advanced markets (Mu and Lee, 2005). Accordingly, it is proposed that less demand opportunity with less variety in demand, high price preferences, and strong barriers to exporting require more investment to gain R&D novelty. Additionally, in-house R&D will play a more critical role than external technological acquisition under conditions of less demand opportunity when a mature value network sets a high entry threshold (Christensen, 1995). Accordingly,

**H1.1. Less demand opportunity leads to R&D decisions oriented towards greater novelty.**

**H1.2. Less demand opportunity leads to R&D decisions oriented towards lower openness.**

Market competition represents the potential of competition, including imitation from latecomers, to trigger technological innovation. High levels of market competition with rapid technological obsolescence and easy product substitution trigger more investment into applied and basic research to fill the competitive gap due to the loss of low labor costs (Kim, 1997; Lee and Lim, 2001; Tang, 2006). At the same time, greater market competition causes a strong requirement for rapid innovation and calls for breaking down the boundaries of R&D organizations and making use of technological diffusion from other related industries (Park and Lee, 2006; Patel and Pavitt, 1997). Hence,

**H2.1. Greater market competition leads to R&D decisions oriented towards greater novelty.**

**H2.2. Greater market competition leads to R&D decisions oriented towards greater openness.**

Technological capability reflects both the status quo of technological innovation (Dosi, 1988; Nelson and Winter, 2002; Rhee et al., 2010) and opportunities for technological innovation in the future (Breschi et al., 2000; Malerba and Orsenigo, 1996). Technological capability plays a fundamentally positive role in the transition from imitation to innovation (Figueiredo, 2002; Kim, 1997) and encourages the development of novel R&D while approaching the international frontier (Chudnovsky et al., 2006; Park and Lee, 2006). The positive effect of technological capability on R&D novelty is based on two perspectives. First, the accumulation of technological capability is path-dependent. Greater technological capability means an accumulation of technological knowledge and management routines, which creates promising conditions for further innovation. Second, existing technological capabilities contribute less to the innovations that are destroying current technological competencies. However, latecomers can only seize technology windows of competence destruction if they possess sufficient technological capability (Lee and Lim, 2001; Park and Lee, 2006). Technological capability has a positive effect
on R&D openness, considering that latecomers with high levels of technological capabilities are inclined to use more in-house R&D to acquire original innovations (Hung and Tang, 2008; Lenger and Taymaz, 2006). Latecomers are forced to use external technologies in earlier stages of catch-up because they are unable to initiate original innovation. However, they will endeavor to increasingly rely on their own R&D efforts to escape being ‘locked-in’ with technological suppliers as they build ever greater technological capabilities (Hobday, 2004, 1995). Therefore,

**H3.1. Higher technological capability leads to R&D decisions oriented towards greater novelty.**

**H3.2. Higher technological capability leads to R&D decisions oriented towards less openness.**

Networking provides the possibility for firms to work in a collaborative mode to acquire external technologies and knowledge rather than relying on firms’ isolated efforts to innovate. Although some researchers consider technological learning to be an aspect of technological capability (Cohen and Levinthal, 1990; Hernández-Espallardo et al., 2011; Kim, 1997; Malerba, 1992; Yam et al., 2004), these concepts are treated separately in this study because technological learning with linkages to external knowledge resources plays an important role in both technological capability building and technological innovation during catch-up (Hobday, 1995; Kim, 1999; Mathews, 2002). Well organized external networks can contribute positively to R&D novelty when considering spill-overs that help firms build risk awareness and avoid technological problems that cannot or would be costly to solve internally (Gilsing and Duysters, 2008; Liu and Buck, 2007; Nieto and Santamaría, 2007). NIE latecomers’ experience also shows that external networks can positively lead to R&D openness, as more investment is directed to various external acquisitions of technology (Cho and Lee, 2003; Park and Lee, 2006). We therefore expect

**H4.1. A wider external network leads to R&D decisions oriented towards greater novelty.**

**H4.2. A wider external network leads to R&D decisions oriented towards greater levels of openness.**

### 2.3. R&D novelty and openness and firms’ innovative performance

Technological laggards in rapidly developing economies need to combine both R&D novelty and openness into a comprehensice decision framework (Kim, 1997; Mahmood and Singh, 2003; Mathews, 2002). These decisions can help latecomers improve their technological capabilities and catch up with more technologically advanced companies.

Catch-up performance is often related to the promotion of industrialization in developing economies (Kim, 1997; Liu et al., 2011; Mathews, 2006; Park and Lee, 2006; Xiao et al., 2013), including such aspects as technological exportation, accelerating the catch-up process, reduction in the technology gap, scientific and technological advancement, accumulation of technological capabilities, and the development of patents (Hobday, 1995; Kim and Lee, 2003; Lenger and Taymaz, 2006; Liu and Buck, 2007; Mathews, 2006; Park and Lee, 2006). These aspects of industrialization cover the requirements of value added from firms’ outputs. Accordingly, we describe a latecomer firm’s performance in sales growth and innovative output as a function of their R&D decision toward novelty and openness.

Greater levels of R&D novelty can create more new knowledge, which in turn creates more opportunities to generate more innovative output, such as IPR and new products (Katila and Ahuja, 2002). However, greater levels of R&D novelty from wider technology categories of new knowledge may increase communication and organization costs when the existing networks of relationships begin to span the internal and external boundaries of the organization (Henderson and Clark, 1990). The stability and reliability of the organization may also decrease (Martin and Mitchell, 1998). Firms might have to invest more time and resources to cope with the increasing complexity of the R&D projects. As a result, they may experience delays in the launching of target markets, thus hindering scale expansion and sales growth. This suggests that

**H5.1. R&D decisions oriented towards greater novelty lead to more innovative output.**

**H5.2. R&D decisions oriented towards greater novelty lead to slower sales growth.**

Greater R&D openness means more external technological acquisition than internal R&D. Those acquired technologies increase the search breadth and thus make it more difficult to launch innovative projects (Laursen and Salter, 2006). Four points support the idea that R&D openness contributes negatively to innovation. First, an organization needs to have a substantial in-house capacity, i.e., absorptive capability, to adopt technologies potentially available from others (Cohen and Levinthal, 1990; Leonard-Barton, 2007). Second, external technological acquisitions may incur high scouting, coordination, and learning costs associated with establishing and maintaining supportive networks (Howells, 2008; Praest Knudsen and Bakker Mortensen, 2011). Third, market transactions involving R&D activities generally imply many shortcomings, including incomplete specification of contracts, lack of adequate protection for proprietary information, and possibilities of lock-in phenomena with technology suppliers (Teece, 1986). Lastly, R&D openness with an increased number of collaborators can increase knowledge leakage (Howells, 2008).

We expect that greater R&D openness, with more external technological acquisitions, reduces opportunities to acquire external knowledge, such as IPR and new product development. A survey of Taiwanese firms demonstrated that technology outsourcing in the form of inward licensing does not contribute to innovation performance (Tsai and Wang, 2009). However, more external technological acquisition can reduce the time to advance the firm’s technological position by assimilating technological developments from benchmarking competitors (Stuart and Podolny, 1996). Furthermore, it reduces the time required to launch innovations relative to internal R&D. The Japanese experience shows that external technological acquisition helps firms to enhance sales in the US market (Mansfield, 1988). We therefore expect

**H6.1. R&D decisions oriented towards greater openness lead to less innovative output.**

**H6.2. R&D decisions oriented towards greater openness lead to quicker sales growth.**

Based on the foregoing discussion, our conceptual model of R&D decision-making during the process of catch-up is illustrated in Fig. 1.

### 3. Research method

#### 3.1. Measures

##### 3.1.1. R&D novelty

The conventional R&D project categorization into basic research, applied research, and development (Link, 1985; Mansfield, 1980;
Peeters and de la Potterie, 2006) is less feasible for the inclusion of imitation-related R&D activities. For this reason, we use a different categorization of R&D projects, including pure science, basic research, applied research, exploratory development, and advanced development (Amsden and Tsang, 2003). These categories are used to calculate the degree of R&D novelty, indicating how much of the R&D resources are allocated to each category.

### 3.1.2. R&D openness

R&D openness emphasizes how R&D activities are organized—whether as formal R&D organizations or informal organizations such as collaborations, technological learning, and technology acquisition (Dosi, 1988; Malerba, 2007; Malerba and Orsenigo, 2000; Teece, 1986). A mixture of different ways to organize R&D enables companies to balance internal and external technology acquisitions (Bauer and Leker, 2013; Malerba, 1992; Timmer, 2003). Accordingly, methods of technological development or acquisition, including in-house R&D, collaborative R&D, technology purchasing, and technology licensing (Bercovitz and Feldman, 2007; Galende and de la Fuente, 2003; Hung and Tang, 2008; Liu and Buck, 2007), are used as an indicator of R&D organization to calculate the degree of R&D openness.

### 3.2. Performance

#### 3.2.1. Innovative output

To capture the characteristics of performance during the catch-up process, we measured the innovative output by the share of turnover from new products and the quantity of IPR (the applications for invention patents and utility models) (Bin, 2008; Lenger and Taymaz, 2006; Osawa and Yamasaki, 2005; Praest Knudsen and Bøtker Mortensen, 2011). Due to the high correlation between the two measurements, innovative output was created as one indicator variable following the data deduction procedure.

#### 3.2.2. Sales growth

Firms’ growth is measured by the sales growth during the last year (Tsai and Wang, 2008; Yam et al., 2004).

### 3.3. Conditions

#### 3.3.1. Demand opportunity

Demand opportunity is measured by the variety of demands (Adner and Levinthal, 2001; Mu and Lee, 2005), demand preferences (Malerba, 1992, 2007), and export opportunities (Hobday, 1995; Kim, 1997).

#### 3.3.2. Market competition

Market competition is measured by the rate of technological obsolescence and ease of product substitution (Tang, 2006).

#### 3.3.3. Technological capability

The current technological capability of a firm is measured by the level of competence and the development stage for technological behavior (Figueiredo, 2002; Hobday, 1995). The starting point is imitation and the assimilation of industry standards by acquiring and learning imported technologies, after which a firm’s technological capability goes through a process of improving, deepening, and upgrading technology, ultimately resulting in the development of strong internal technical capabilities that allow the company to compete at the technological frontier.

The future technological capability of a firm is measured by the level of awareness of threats and opportunities in a number of stages (Rush et al., 2007). The first stage is an unawareness stage, characterized by a fire-fighting crisis style of innovation. The second stage is a reactive stage, characterized by clear recognition of continuous improvement but with no idea of how to make improvements most effectively. This is followed by a strategic stage, characterized by a well-developed sense of technological development and the implementation of new projects and continuous innovation. The final stage is creative and is characterized by well-developed sets of technological capabilities to proactively define the international technology frontier. To some extent, the levels of competency, technological behavior, and awareness overlap and supplement one another (Hung and Tang, 2008). This paper uses all three indicators to measure technological capability.

#### 3.3.4. External network

The external network is measured by various institutional arrangements or sources of technological learning, including foreign direct investment, joint ventures, licensing, OEM, ODM, contracts, and technological alliances (Cho and Lee, 2003; Hobday, 1995).

### 3.4. Sample and data collection

The variables and indicators were obtained from the literature, and some had not yet been validated. A pilot study was implemented to assess the validity of the constructs and verify their translation into Chinese. The final standardized questionnaire contains three parts. Part 1 contains questions about the conditions of innovation. The indicators of demand opportunity and market competition are rated on 5-point Likert-type scales ranging from 1 = strongly disagree to 5 = strongly agree. Indicators of technological capability take the form of single-choice questions, whereas those of external networks are studied using multiple-choice questions. Part 2 contains questions about R&D decisions with the constructs of percentages of investment in specific categories of R&D projects and various external technology sourcing modes. Part 3 contains questions about catch-up performance, asking how much of the company’s performance was obtained as a share of turnover from new products in the previous year, sales growth during the previous year, and the number of applications for invention patents and utility models within the previous year. Respondents were asked to provide real data for all indicators when answering the questions.

The questionnaire was sent to the R&D managers of Chinese firms in industrial parks in Zhejiang, Jiangsu, Shandong, Sichuan, Xinjiang, and Neimongol. The sample consists of firms that have implemented a product or process innovation within the last three years, reflecting the OECD definition of an innovative firm (OECD, 2012). The survey was initiated in February 2008 and completed in March 2008. We received 343 responses, of which 279 (or 81.3%) were valid.
All valid questionnaires were completed by the director of technology or innovation in the responding company. The annual sales of the sample firms ranged from less than 50 million RMB to more than 20 billion RMB. Sixty-two of the respondent companies were established after 2002 (22.2% of the whole sample), 130 were established between 1992 and 2001 (46.6%), and 37 were established between 1978 and 1991 (13.3%). The remaining 29 firms were established before 1977 (10.4%). For the industry distribution of the respondents, we used the Pavitt categorization (1984): 43 sample firms belonged to supplier-dominated industries (representing 15.4% of all firms); 38 firms to specialized supplier industries (13.6%); 45 firms to scale-intensive industries (16.1%); 122 firms to science- and technology-driven industries (43.7%), and 31 firms to information-intensive industries (11.1%).

4. Analysis of the structural equation model

4.1. Measurement validation

We used such methods as factor analysis and the coefficient of variation to validate our framework. The reliability of variables was assessed in the following two ways.

First, traditional reliability measures were used to assess variables such as demand opportunity, market competition, and technological capability. Cronbach's alpha for each variable was calculated and found to exceed 0.8, thereby satisfying the requirements recommended by Hair et al. (2010). Without any modifications, these three variables showed sufficient reliability and sound internal consistency within each set of indicators.

Second, a two-step approach was used for the reliability measurement of R&D novelty and openness according to index response theory. As a first step, we calculated the percentage of samples with a value of zero. This step led to the elimination of the indicator of pure science investment percentage (64% containing zeros), revealing low levels of identification by respondents. The percentages of pure science investment and basic research investment were merged into a new indicator labeled 'basic research', as there is little difference in the definitions for these two indicators and the sum of all indicators for novelty must be 100%. The coefficient of variation of each indicator was then calculated according to the formula below:

\[ V_i = \frac{S_i}{\bar{X}} \quad \text{with} \quad \bar{X} = \frac{1}{n} \sum X_i \quad \text{and} \quad S_i = \sqrt{\frac{1}{n-1} \sum (X_i - \bar{X})^2} \]

The results show that the \( V_i \) value of each indicator is greater than 0.5, indicating that a large percentage of the information is reflected by these indicators with a high degree of statistical validity. Accordingly, R&D novelty and openness show sufficient reliability. The degree of innovation, innovation speed, IPR, and external network were not validated because they were introduced in the questionnaire as a single indicator. In summary, the results suggested that the model adequately fits the data and that the testing of the structural model was appropriate.

4.2. Calculation of novelty and openness in R&D decisions

R&D novelty and openness are the comprehensive results of resource allocation for all types of R&D projects or external technology acquisition modes. It is difficult to obtain their values by the statistical analysis of factor reduction or the estimation of indicator models. Therefore, a method of weighted averages was used to calculate the values of these two variables with weights calculated using the analytical hierarchy process (AHP) (Calderini and Garrone, 2001).

The targets were established separately as novelty and openness. The criteria for evaluating novelty are short-term profit and innovative potential, while taking into account the need for a balance between short- and long-term developments (Calderini and Garrone, 2001; Patel and Pavitt, 1997; Raider, 1998).

The alternative approaches for obtaining targets of novelty and openness are also used separately as indicators. The judgment matrix was created through a standard expert investigation table with a 9-point scale method sent to five academic experts and five business experts.

Tables 1 and 2 below show the results for the calculation of these two variables. To calculate the value of R&D novelty, the weight of advanced development investment is 0.13, the weight of exploratory development investment is 0.14, the weight of applied development investment is 0.22, and the weight of basic development investment is 0.51. To calculate the value of R&D openness, the weight of in-house R&D investment is 0.13, the weight of collaborative R&D investment is 0.15, the weight of technology purchasing investment is 0.27, and the weight of technology licensing investment is 0.45. The results were highly consistent, and the calculated weights had coefficients of random consistency ratio (CR) of less than 0.1.

4.3. Model testing and estimation

The estimation of the model variances of error for the single-indicator variables was accomplished with preinstalled values. Two methods were considered. The first method was to calculate the variance of error with a value of 0.8 as an indicator of reliability (Hair et al., 2010). The other method was to set the variance of error to 0, assuming the use of well-developed indicators for these variables. Seven alternative structural equation models were developed using these two methods. Following a comparison of the model fit indices, the final model was fixed with 0 as the variance of error for all single-indicator variables except the two intermediate variables, R&D novelty and R&D openness, which were set without preinstalled values. The fit indices CFI, NFI, and RFI all exceeded or approached 0.90. Furthermore, all estimations of the residuals were significant at the 0.01 level except for one estimate that was significant at the 0.05 level. Therefore, the overall fit of the model was satisfactory.

Table 1
AHP result of R&D novelty.

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<th>( W_i ) of index</th>
<th>( W_o ) of rule</th>
<th>Short-term profit</th>
<th>Innovative potential</th>
<th>Weights</th>
<th>C.I.</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of advanced development investment</td>
<td>0.5477</td>
<td>0.0438</td>
<td>0.17</td>
<td>0.0438</td>
<td>0.13</td>
<td>Short-term profit</td>
</tr>
<tr>
<td>Percentage of exploratory development investment</td>
<td>0.2963</td>
<td>0.1057</td>
<td>0.14</td>
<td>0.1057</td>
<td>0.22</td>
<td>Innovative potential</td>
</tr>
<tr>
<td>Percentage of applied development investment</td>
<td>0.1345</td>
<td>0.2443</td>
<td>0.51</td>
<td>0.2443</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of basic development investment</td>
<td>0.0415</td>
<td>0.6062</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2
AHP result of R&D openness.

<table>
<thead>
<tr>
<th>Wᵢ of index</th>
<th>Wᵢ of rule</th>
<th>In Innovation speed</th>
<th>IPR</th>
<th>Weights</th>
<th>C.I.</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of in-house R&amp;D investment</td>
<td>0.0420</td>
<td>0.83</td>
<td>0.17</td>
<td>0.13</td>
<td>0.070</td>
<td>0.074</td>
</tr>
<tr>
<td>Percentage of collaborative R&amp;D investment</td>
<td>0.1210</td>
<td></td>
<td>0.284</td>
<td>0.15</td>
<td>0.070</td>
<td>0.074</td>
</tr>
<tr>
<td>Percentage of technology purchasing investment</td>
<td>0.3128</td>
<td></td>
<td>0.0842</td>
<td>0.27</td>
<td>0.070</td>
<td>0.074</td>
</tr>
<tr>
<td>Percentage of technology licensing investment</td>
<td>0.5242</td>
<td></td>
<td>0.0508</td>
<td>0.45</td>
<td>0.070</td>
<td>0.074</td>
</tr>
</tbody>
</table>

Fig. 2. Results of the structural equation model (parameter estimates were derived from the completely standardised solution).

5. Results

The results of the AMOS estimation are summarized in Fig. 2. Of the twelve hypotheses tested, four were rejected because their estimates were not significant. The results are presented in the section below, and the findings are discussed in Section 6.

First, we examine the impact of demand opportunity on novelty and openness. As proposed by hypotheses 1.1 and 1.2, low demand opportunity with a low variety of needs, high price preferences, and strong barriers to exporting lead to greater R&D novelty but less R&D openness due to the difficulty of entering a mature value network. Fig. 2 shows that demand opportunity has a negative impact on R&D novelty and no effect on R&D openness. Accordingly, hypothesis 1.1 is supported, but hypothesis 1.2 is rejected.

Next, we focus on the effect of market competition on novelty and openness. As proposed in hypotheses 2.1 and 2.2, greater levels of market competition with rapid technological obsolescence and ease of product substitution lead to greater R&D novelty. In Fig. 2, there is no significant relationship between the market competition and R&D openness, so we reject hypothesis 2.2. Market competition has a significant positive effect on the novelty of R&D. We discuss these results in more detail in the Section 6.

Third, we assess the impact of a firm’s technological capability on novelty and openness. As proposed in hypotheses 3.1 and 3.2, greater levels of technological capability lead to greater R&D novelty but less R&D openness. In Fig. 2, both relationships are supported by the estimation. Of all factors contributing to R&D decisions, technological capability had the highest coefficients for both R&D novelty and openness, which may indicate an effect of path-dependent or myopic technology development (Timmer, 2003).

The final determinant of openness and novelty is the external network of innovating companies. As proposed by hypotheses 4.1 and 4.2, external networks should contribute positively to R&D novelty and openness. In Fig. 2, the external network of responding firms has a positive effect on R&D openness, confirming H4.2, but no significant impact on R&D novelty.

As proposed in hypotheses 5.1 to 5.2, greater levels of R&D novelty with more investment in new knowledge-creating projects should lead to slower sales growth and more innovative output. In Fig. 2, R&D novelty has a highly significant effect on innovative output, as expected. However, there is a significant positive relationship between R&D novelty and sales growth, contrary to hypothesis 5.2 (see also Section 6).

Finally, we focus on the effect of R&D openness on the two forms of performance output. As proposed by hypotheses 6.1 to 6.2, greater R&D openness with more investment in external technological acquisitions contributes to increased sales growth but leads to less innovative output. These two relationships are confirmed in Fig. 2.

As the data we gathered include heterogeneity factors, we conducted further tests on the moderating effects of firm age and industry type on the relationship between R&D novelty (or openness) and firms’ innovation performance. We find that only firm age has a significant positive moderating effect on the relationship between novelty and innovation output and a significant negative moderating effect on the relationship between novelty and sales growth. This finding implies that younger firms tend to be more innovative and have higher innovative output but lower sales growth, as they are new to the market. The other heterogeneity factors had no significant moderating effects. For brevity, the results are available upon request.

6. Discussion and conclusion

In this study, we explored the characteristics of R&D decisions during technology catch-up using a structural equation model with survey data collected from local companies in China. Two strategic dimensions of R&D decisions, novelty and openness, were studied to explain latecomers’ innovation performance. Several mechanisms directing the R&D decisions were corroborated by the data. First, high levels of R&D novelty, with investment in new knowledge creation, contribute positively to innovative output and sales growth. We expected a negative relationship between R&D novelty and sales growth but found a significant positive relationship, which might be explained by the fact that the respondents who are involved in R&D novelty are also adopting organizational mechanisms to accelerate the innovation process so that the assumed trade-off in budget allocation does not occur.
Second, greater R&D openness, with greater investments in external technology acquisitions, contributes positively to sales growth but negatively to innovative output, as expected. The impact of R&D openness on the two innovation outcome variables indicates that open innovation is a concept that should have a prominent place in the study of catch-up strategies of companies in rapidly developing economies. Firms that are involved in more explorative external search activities may be less active in radical innovation.

R&D novelty and openness are in turn affected by a number of factors. R&D novelty is positively affected by a firm’s market competition, technological capabilities, external networks, and reduced demand opportunities. Market competition has a positive effect on novelty, as firms strive to improve competitiveness when market competition becomes more intensive. It has no impact on R&D openness, although we expected a positive effect. Furthermore, R&D openness is unaffected by demand opportunity but positively affected by external networks. This finding implies that external networks do foster R&D. However, external networks do not necessarily lead to R&D novelty, as the result indicates that it had no direct effect on novelty. This finding may indicate that the extent to which technologies are acquired from external sources is related to the variety of external institutional arrangements or sources of technological learning (defined here as external networks). This result is similar to the situation described by Laursen and Salter (2006), namely, that the search depth and breadth dimensions of firms’ innovative performance is affected by how often they exploit their existing knowledge and how widely they explore new knowledge through different channels. This external knowledge acquisition process requires firms to learn how to identify suitable external channels and extract knowledge from them on a trial-and-error basis (Katila and Ahuja, 2002). Chinese firms intensively invest in and use external sources, such as in-licensing arrangements, resulting in less attention being devoted to fostering technological absorptive capability during this external sourcing process. They might encounter difficulties in moving toward R&D novelty after making such substantial commitments.

Next, R&D openness is negatively affected by technological capability, which indicates that Chinese companies in-source technologies when they lack technological competencies and that reliance on external technology decreases when they can rely on stronger internal technological capabilities. Finally, market competition plays a contradictory role in R&D novelty and openness. Market competition has no impact on R&D openness, although we expected a positive impact. This surprising result suggests two related issues. First, intensive market competition increases the risk of unintended technology spillovers, so firms will be less inclined to open up R&D with others. Second, it also indicates that Chinese companies are developing technological innovations that are directly relevant to their market position, compared to science-based, precompetitive research, where collaboration is possible without immediate repercussions on the market position of the companies.

Several managerial implications can be drawn for R&D decision-making processes when latecomers try to catch up. Firstly, it is worth considering a reasonable level of investment in development projects to accumulate absorbing capabilities that augment innovative output, which is mainly acquired through such projects. Furthermore, a sound mixture of R&D investment structure without sacrificing development projects contributes to the sales growth aimed at short-term competition. Second, greater R&D openness with more investment in technology purchasing enhances sales growth. However, there is a cost, as the innovative output is negatively affected by R&D openness. Third, demand opportunity has a negative impact on R&D novelty and no effect on R&D openness. Therefore, when facing major demand opportunities characterized by diversified needs and high price preferences, investing more in acquiring diversified technology rather than absorbing technologies is recommended. Fourth, the effects of market competition on R&D decisions are mediated by technological capability, as inferred previously. When there is a high level of market competition and low technological capability, it is worth investing more in new knowledge creation with greater R&D novelty to differentiate the product or services to survive and better compete. Fifth, technological capability plays a decisive role in R&D decision-making. Accumulation of technological capability, which should not be confined to absorbing abilities for imported technologies, is a good way to avoid myopic technological development and reap more profits from newly created knowledge. Finally, we suggest that external networks are a channel for finding alternative external technological acquisitions in the short term. This may not necessarily lead to R&D novelty, and it is worth paying attention to the accumulation of innovative output during this process. In summary, structurally balanced R&D decisions on both dimensions of novelty and openness are critical for achieving good catch-up performance. Starting from the specified conditions of innovation, both short- and long-run innovation objectives should be considered in R&D decision-making.

This paper has its limitations. Because many new indicators are used here, it is difficult to study such a new topic using a limited number of firms. Moreover, more work is needed to refine and test these new indicators, such as R&D openness and innovation speed, which are based on theoretical analysis and explorative case studies. Finally, the conceptual model was built on previous generic theories. We have made an attempt to link it with Chinese firms’ technological catch-up processes. Further empirical tests using samples from other countries might be needed to generalize the conceptual model.

Despite the limitations mentioned above, this paper provides a good starting point to resolve the dilemmas inherent in the R&D decision-making when companies in rapidly developing economies try to catch up. According to the discussion of the results, two topics emerge for future study. One is the role played by internal technological capability, which needs to be deconstructed to analyze its relationship with R&D novelty and openness in greater detail. The other is also related to technological capability, but with an emphasis on how to avoid the myopic development of technology by R&D investment according to specific conditions of market demand and competitiveness levels.

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