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OPEN INNOVATION

Yufen Chen and Wim Vanhaverbeke

Concept and connotation of open innovation

A conceptual comparison of open innovation and several similar innovation models

Open innovation

Chesbrough (2003a) first introduced the open innovation model in 2003. In the model, valuable ideas can be gained from both inside and outside the company, and the commercialization process can take place either inside or outside the company (Chesbrough, 2003b). The open innovation model elevates the importance of external ideas and external commercialization channels to the same level as that of internal ideas and internal commercialization channels (Chesbrough, 2003a). Chesbrough proposed the model mainly in response to the traditional NIH (not invented here) attitude that exists in some large American corporations with strong R&D capabilities.

In the open innovation paradigm, the boundaries of corporates are permeable. Innovative ideas mainly come from R&D and other departments inside a company but may also come from outside the company. Innovative ideas generated inside a company may spread to the outside at any stage of the R&D process through knowledge flow, the movement of personnel, or patent transfer. Some research projects that do not fit in the current business lines of a company may produce tremendous value somewhere else in the market and may be commercialized through external channels. Companies no longer keep their intellectual assets locked in a safe. Instead, they find good uses for them in other companies and gain profits from such assets through licensing agreements, short-term partnerships, and other arrangements (Chesbrough, 2003b).

The open innovation model has changed the NIH mind-set. The model demands that companies make full use of the abundance of external knowledge resources, search for suitable external technologies that will compensate for a lack of internal innovative resources, strive to integrate internal and external technologies, and thereby create new products and services. In the open innovation model, external knowledge complements internal knowledge and plays an equally important role. At the same time, the open innovation model has overcome the prejudice of NSH (not sold here). Companies can commercialize their internal technologies

through external channels and thereby maximize returns on R&D investment. The new thinking represented by open innovation has helped us find new approaches to value creation and profit making.

The open innovation model refers to a type of innovation model in which a company in the technology innovation process can simultaneously make use of internal and external complementary resources. The commercialization process of internal technologies can take place inside or outside the company, and the company is engaged in multifaceted and dynamic cooperation with various partners at each stage of the innovation chain. Chesbrough (2006) redefined the concept of open innovation as an innovative paradigm in which companies intentionally make use of inbound and outbound knowledge flows to speed internal innovation or expand knowledge development in external markets.

Open innovation emphasizes the importance to cross organizational boundaries that companies carry out open cooperation with outside organizations and make use of external innovative resources and external marketing channels to improve innovation efficiency. The open innovation model has changed the way in which companies gain the resources necessary for achieving innovation. In the open innovation model, the boundary of a company is permeable. Companies cannot only rely on their own resources and must use the innovative resources of the outside environment, and so a huge knowledge exchange network linking internal company units and various external organizations takes shape. The features of the open innovation model make it possible for a company to be engaged in exploratory and exploitative learning simultaneously.

The concept of open innovation is a microscopic concept of the innovative system of an organization. It is derived from a summary of the innovation modes that result from autonomous adjustments made by companies to adapt their innovative processes to complexity in an innovative and rapidly changing knowledge economy. In an era of knowledge explosion, even companies with the largest knowledge reserves cannot achieve self-sufficiency in all areas of technology, and thus open innovation has become the inevitable choice for effective innovation by individual organizations. Improving the openness of a company's innovation system; enhancing its capabilities in knowledge search, knowledge acquisition, knowledge absorption, and knowledge utilization; and providing feedback to strengthen internal R&D capabilities are the preconditions for achieving independent innovation and collaborative innovation. Open innovation is also the precondition for achieving synergies within the national innovation system.

Collaborative innovation

The concept of collaborative innovation is a macroscopic concept within the processes of the national innovation system. The concept of synergy derives from the synergy theory (Haken, 1978), which is an important branch of complex systems theory. The idea of synergy comes from the study of open systems in physics. The synergistic effect converts a complex system into an orderly system and, in the process, produces a tremendous amount of energy. The concept of collaborative innovation was proposed by Peter Gloor, a researcher at the MIT Sloan Center. According to Gloor, collaborative innovation is a process in which "a networked group of self-motivated people form a collective vision, and then exchange ideas, information and work statuses through the network, and work collaboratively to achieve their common goals" (Chen, 2012). The concept of collaborative innovation leads us to a path through which China can transform itself into an innovative country. To build a vibrant national innovation ecosystem, we must rely on the full collaboration of the government, industries, academia, research institutes,

and other innovative entities; build an open network of knowledge generation, knowledge transfer, and knowledge utilization within the national innovation system; and so eventually achieve the strategic goal of independent innovation.

Open innovation in network-based crowdsourcing mode

Network-based crowdsourcing refers to the practice by a company or organization of outsourcing tasks that used to be performed by its own employees to a crowd of nonspecific network users (usually users in a large-scale network) in the form of free and voluntary transactions (Howe, 2006). The network-based crowdsourcing model differs from the traditional outsourcing model in that the traditional model is a mode of transactional cooperation between organizations, in which a company enters into contracts and purchases services from specific organizations. But network-based crowdsourcing is a mode of contractual cooperation between a company and a crowd of network users, in which the objects of cooperation are no longer specific cooperative companies but network users across the globe (and thus the geographic scope of the cooperation expands globally). On the basis of the nature of the tasks, the modes of network-based crowdsourcing can be divided into two categories: information-processing-oriented modes and R&D-and-innovation-oriented modes. These modes are based on the nature of the collaboration among network users and can be divided into cooperative and competitive network-based crowdsourcing.

Open innovation in the network-based crowdsourcing model refers to a mode of operation in which a company takes advantage of the information network shaped by the various online platforms to carry out knowledge search and knowledge matching, collaboration among the many participants, exchange of funds and knowledge, and knowledge absorption and utilization. Simply put, when faced with a technological challenge, the company first formulates a specific technological issue through the technical process and makes an assessment about a reasonable price to pay for resolving the issue. The company then publishes an invitation to bid to network users around the globe through a network-based crowdsourcing platform. Under the supervision of the platform, the company can then choose from among the various solutions submitted. In the process, network users develop solutions through a cooperative or competitive process, so the proposer of the best solution is rewarded and the company obtains the best solution. Given that a network-based crowdsourcing platform can directly access the capabilities of the mass and the various repositories of resources and repositories of ideas, its value and efficiency can greatly exceed those of what can be integrated into any individual company (Schenk and Guittard, 2011). The network-based crowdsourcing model is the most open innovation paradigm for cheaply absorbing high-end innovation resources across all regions, cultures, and technical fields.

In summary, independent innovation is a concept related to the goal of constructing a national innovation system. Collaborative innovation is a macroscopic concept related to the process for constructing a national innovation system, and open innovation is a microscopic concept at the organizational level. In other words, independent innovation is regarded as the strategic objective. Collaborative innovation is the approach for fulfilling the objective, and open innovation is a precondition for fulfilling the objective. Only when a large number of innovation entities attach greater importance to open innovation can we be successful in stimulating a flow of knowledge and promoting the development of synergies among industries, academia, and research institutes – and so enhance our capabilities in independent research to become an innovative nation.

Classification of the modes of open innovation

To distinguish the concept of open innovation from the concepts of innovation network and technology alliance, open innovation is divided into two categories based on the direction of knowledge flow and process direction: inbound open innovation and outbound open innovation (Chesbrough and Growther, 2006). Inbound open innovation refers to the process by which a company absorbs external knowledge and integrates external knowledge, creative ideas, and technologies of value with internal ideas so as to carry out innovation and commercialization inside the company. Outbound open innovation refers to the process through which a company, as the source of innovation, exports its internal knowledge, technology, and creative ideas to external organizations – and the commercialization of such knowledge, technology, and ideas then takes place in external organizations (Wang, 2010).

From the perspective of business processes, Gassmann and Enkel (2004) surveyed 124 companies based on the direction of knowledge flow and proposed three types of open innovation: (1) outside-in open innovation (which emphasizes the integration of suppliers, customers, and other external knowledge sources to expand the knowledge base of the company, improve its internal R&D, and enhance its innovative capabilities); (2) inside-out open innovation (which emphasizes “pioneering” to promote the internal knowledge of an organization to the outside and exporting creative ideas through the sale of intellectual property so as to achieve the external commercialization of internal creative ideas); and (3) coupled open innovation (which emphasizes creating complementary knowledge together with strategic partners and jointly developing and commercializing creative ideas through long-term alliances, cooperation, joint ventures, and other means so as to gain advantages with both inbound and outbound knowledge flows).

Dahlander and Gann (2010) classified open innovation into four types on the basis of the direction of knowledge flow and whether or not economic transactions are involved: inbound sourcing, inbound acquiring, outbound revealing, and outbound selling. Among the four types, the inbound sourcing type of innovation involves economic transaction, and the inbound acquiring type of innovation does not involve economic transaction. The research on outbound innovation revealing mostly concerns the inbound acquiring type of innovation.

Laursen and Salter (2006) were the first to point out that openness should be measured for the inbound acquiring type of innovation and proposed a method for measuring openness, which has been referenced by many scholars. On the basis of their work, Chen and Chen (2008a) expanded on the measurement of inbound openness from the perspectives of technology-driven and experience-driven industries. However, the research on openness mentioned earlier is limited to inbound openness without considering the outside commercialization of the internal knowledge of a company. Henkel, taking embedded Linux as an example, carried out the first initial exploratory study of outbound openness (Wang, 2010). Lichtenthaler (2009a, 2009b) studied open innovation of the outbound selling type. Their study helped them conclude that the external commercialization of a company’s internal technology holds great strategic importance to the success of the company.

Essential connotation of technological innovation

Schumpeter was the first to propose innovation theory from the perspective of economics. Schumpeter argues that innovation refers to the introduction of an unprecedented “new combination of production factors” into production systems – and the aim of innovation is to

obtain profits (Schumpeter, 1934). What is special about Schumpeter's definition of technological innovation is the emphasis on the effective combination of economic factors and that technological innovation should be regarded as the organic combination of economic factors (such as information, talented people, material capital, and entrepreneurial ability) to produce a unique usefulness. He specifically distinguishes invention from innovation. If an invention has not found its practical application, it is economically ineffective.

From the perspective of business management, technological innovation is a process from the generation of new ideas to research, development, trial production, actual production, and initial commercialization. Technological innovation means the combination of invention, development, and commercialization that turns a creative idea into reality and carries a concept to the market for commercialization.

Technological innovation emphasizes the integration of technology and market

Technological innovation is an economic activity that aims to turn a creative idea into a commercial success. That is to say, it must meet the needs of society and the market. The indication of the success of a technological innovation project is the initial commercialization of the technological invention. Technological innovation is the combination of technology and market, and neither is dispensable. If a company is always pursuing "technical perfection" without fully taking changing market factors into account, even the most advanced technology will fail to produce successful innovation (Chen and Liu, 2006). Technological leadership is no guarantee of successful innovation, and sometimes it even hinders innovation. There is no intrinsic value in technology itself, and value only emerges when we commercialize technology through some business model (Chesbrough, 2003a). An innovative product in any type of business must ultimately be oriented toward its market to meet the needs of users. Only when an invention has been transformed into economic activities and has produced significant profits can it be regarded as a technological innovation.

Technological innovation emphasizes the effective integration of the R&D, manufacturing, and marketing departments

Difficult passages across the Darwinian seas must be successfully navigated in the process of turning an innovative technology into a popular product. The uncertainty of technological innovation is also reflected in market and business strategy. The failures of most technological innovation projects are not caused by failures in technology, but by shortcomings in market research, sales, and organizational management. Therefore, to succeed with technological innovation, we must successfully coordinate R&D, marketing, and production. Technological innovation is not just the work of the R&D department. Instead, innovation must reach deep into the organization and every root and branch of the company.

Technological innovation emphasizes the effective integration of internal and external knowledge

Technological innovation requires knowledge and technologies from an increasing number of fields of study, and the comprehensiveness and complexity of innovation increases day by day. For companies with limited resources, it is not enough to rely on their own resources to enhance innovative capabilities because such resources no longer meet the needs of current

technological innovation. Individual companies are not strong enough to internally produce all the knowledge needed, and it is impossible for them to have all the resources and technologies required for innovation (Teece, 1986). An external knowledge source is usually the key element in an innovation process (Cohen and Levinthal, 1990). Therefore, to gain and maintain competitive advantage, the ability to adapt, integrate, and configure internal and external technological resources is important (Teece, Pisano, and Shuen, 1997). The ability to make effective use of external resources has become a key component of a company's innovative capability (Cohen and Levinthal, 1990).

Two modes of technological innovation

Professors Jensen and Lundvall proposed two modes of technological innovation: the STI mode, which is focused on science, technology, and innovation; and the DUI mode, which is based on learning by doing, using, and interacting (Jensen, Johnson, Lorenz, and Lundvall, 2004). At the same time, they pointed out that the perfect combination of STI and DUI modes would greatly enhance innovative capability and that it is insufficient to just focus on one of the two modes.

Innovation mode is based on scientific research or R&D; the innovation process goes from basic research, applied research, experimental development, trial production, actual production, and eventually to commercialization. The successful application of this innovation mode usually requires strong R&D and technology capabilities. With adequate human and material resources for R&D, a company can rely on its own effort to explore and achieve breakthroughs in core technologies. On the basis of such breakthroughs, companies can again rely on their own technological capabilities to complete the development of new products and successfully commercialize such products. Innovation modes based on scientific research are highly dependent on R&D activities. Internal R&D capability is a strategic asset of an enterprise, but innovation modes based on scientific research are not simply technology-driven linear processes. A company in this mode of innovation must still emphasize the integration of scientific research and industrial and market chains – which is dictated by the nature of technological innovation.

The experience-based innovation model refers to a process in which employees and users encounter problems when producing and using the product, and the company, with its existing technological capabilities, implements R&D in collaboration with universities or research institutes to search for solutions to problems – and thereby achieve technological innovation. In the solution searching process, employees or users gain technological knowledge or abilities. If this process is rather complicated, finding solutions will require interactions among members of a team or among members of different teams, and thus there will be many instances of experience sharing and knowledge sharing. The successful application of this innovation mode requires that employees and users have a sense of responsibility and the necessary technical skills, which in turn requires that employees adopting this mode of innovation must be well qualified in terms of scientific training. This innovation mode relies on continued improvements in the practical setting to increase the efficiency of technology, and thus the accumulation of experience plays a key role. The focus of this innovation mode is on users, rather than just products or core technologies. Effective innovation in noncore technology areas can also improve innovation performance and economic competitiveness, and represents an effective approach for technology accumulation.

The combination of STI and DUI modes can increase efficiency in the use of innovative resources and improve innovation performance (Jensen, Johnson, Lorenz, and Lundvall, 2004). Jensen et al., illustrate the importance of combining these two innovation modes with examples of technological innovation in Nordic countries. Innovation in STI mode requires considerable

R&D investment and energetic R&D activities, but it does not mean that DUI mode can be ignored. Similarly, DUI mode must be based on STI mode. Technological opportunities and market conditions are changing rapidly in a global economy, and everything must be considered for achieving innovation: from the development of core technologies to the market, user needs, user experience, and so on. Companies must fully grasp the rules of technological innovation and coordinate internal R&D, technology matching, manufacturing, and external factors such as the market. The combination of STI mode and DUI mode ensures the effective use of national scientific resources to speed up the advancement of science and technology and industrialization. Capabilities in technological innovation can be enhanced by combining internal R&D, searches, and external innovative resources

External source theory of technological innovation

Since the 1980s, the seismic changes in technology and breakneck advancement in telecommunications and intensification of global competition have meant that manufacturers must continuously innovate to maintain competitive advantages (Hage and Alter, 1993; Brown and Eisenhardt, 1998). Highly complex innovations often involve multiple technological fields, particularly in the automotive, electronics, telecommunications, and aeronautics industries. It is usually necessary to combine knowledge from a variety of sources for rapid and continued product development (Hagedoorn, 1993; Chung and Kim, 2003). It is difficult for any individual company to engage in simultaneous research in all key technological areas, and thus few companies can maintain a leading position in every area of technological research. No individual companies are strong enough to internally produce all the knowledge needed for technological innovation, and it is impossible for companies to obtain all the resources and technologies needed for such innovation (Teece, 1986; Caloghirou, Kastelli, and Tsakanikas, 2004). It is therefore worthwhile for companies to interact with external organizations to gain new scientific and technological knowledge (Mowery, Oxley, and Silverman, 1996).

For effective innovation and development, a company must pay more attention to its external environment and place more emphasis on integrating various resources. Most research in innovation management has stressed the importance of learning and technology search for interdisciplinary innovation through interactions between organizations. Nelson and Winter (1982) proposed a decision-making process for new technology searches outside the organization. Teece (1986) pointed to the importance of complementary assets for innovation success and explained why innovative companies often fail to gain the first mover advantage – while fast followers often make enormous profits. Teece pointed out that innovation pioneers lacking in complementary assets must acquire manufacturing and marketing capabilities from the outside through cooperation and integration for the successful commercialization of new products.

Cohen and Levinthal (1989) emphasize that R&D cannot just produce new knowledge and encourage innovation and must also improve a company's capacity to absorb knowledge from the external environment. External knowledge sources represent the key factor in the effort to attain success in innovation (Cohen and Levinthal, 1990). Rosenberg (1990) questioned why companies invest in fundamental research and found that fundamental research can enhance their ability to make good use of external scientific knowledge. Rosenberg sees fundamental research as an "admission ticket" to information networks for monitoring and evaluating external technologies, and he believes that companies that are bad at using external knowledge are at a competitive disadvantage. Innovation sources are greatly varied according to von Hippel (1988), and he specified four external sources of innovation: users and suppliers, universities and research institutes, competitors, and other countries. Rothwell's

fifth-generation technological innovation process suggests that integration of the system and expansion of the network model is an innovation process with multiple factors that requires a high degree of integration of both intra- and intercompany resources (Rothwell, 1994). Knowledge base theory emphasizes the importance of knowledge-based and learning-based interactions between internal elements and external elements of an organization. It holds that any important resource that can enhance the innovative capabilities of a company, regardless of whether inside or outside the company, should be incorporated into the company's system of capabilities (Nonaka, 1994). The core competitiveness of a company is increasingly dependent on its capabilities when searching for knowledge, creating knowledge, and making technological innovations (Powell, 1998). Scholars in organizational theory and structural sociology who hold an open system view (Wellman, 1988) have long insisted that the most important part of an organization's environment is the social network of its external links and any economic activity in open systems. Key resources other than those owned by the company itself can be obtained by various forms of links to external entities. Thus, various links of different forms between companies can produce considerable relational rent and competitive advantages (Dyer, 1996). Although these articles do not include the term "open innovation", they nevertheless all contain the idea of "openness".

The idea that a company can facilitate its technological innovation with resources acquired externally has attracted the attention of many experts in innovation management. In the past, outsourcing was regarded as a disadvantage to a company. But with the changes in the competitive environment, resource outsourcing has become a key factor for the successful operation of an intelligent business. The creation of capabilities in new technological areas is a dynamic learning process for a company that requires the combination of external technology acquisition and internal technological activities (Granstrand, Patel, and Pavitt, 1997). The integration of internal and external technological resources is the key dimension of an effective innovation strategy. A successful company, on the basis of its own capabilities, investment, and decision process, can always strive to take advantage of both internal and external technologies to maintain and strengthen its competitive advantages (Wheelwright and Clark, 1992).

Impact of open innovation on innovation performance

Company boundaries are permeable in the open innovation paradigm. Valuable creativity can be obtained from inside and outside a company, and the commercialization of such ideas can take place inside or outside the company. The open innovation system can reduce the uncertainty of technological and market innovation and help the company avoid the dilemma of innovation.

The open innovation mode proposed by Chesbrough has become a popular research field in the international academic community and received recognition from scholars at home and abroad (Gassmann and Enkel, 2004; Christensen, 2005; Vanhaverbeke, 2006; Gassmann, 2006). In addition to being suitable for companies in R&D-intensive high-tech industries, open innovation mode is suitable for mature and low-tech industries (Chesbrough and Crowther, 2006; Vanhaverbeke, 2006; van de Meer, 2007; Spithoven, 2011). In addition to large corporations, open innovation is equally suitable for small and medium-sized enterprises (van de Vrande, Lemmens, and Vanhaverbeke, 2006; van de Vrande et al., 2009; Spithoven, 2011). Open innovation has also been introduced to service-related innovation in areas of business management (Chesbrough, 2011).

How did the open innovation paradigm affect the development of a company's innovative capabilities? And how has it become the focus of both academia and industry? There are three research conclusions about the impact of open innovation on innovation performance.

Positive impact

Lichtenthaler (2009a) pointed out that open innovation has a positive impact on enterprise performance, but patent protection is bad for open innovation. Based on data gathered from Austrian companies, Todtling, Lehner, and Kaufmann (2009) concluded that external cooperation in the innovation process has a significant impact on the performance of new product-related innovation. Yeoh (2009) argues that companies can absorb different types of knowledge through R&D-based cooperation, and companies can be more effective in acquiring technology and knowledge by interacting with external knowledge sources to improve innovation performance. The number of exploratory cooperative alliances has a significant impact on company performance (Yamakawa, Yang, and Lin, 2011). Chiang and Hung (2010) believe that broad openness is good for breakthrough innovation, and the depth of openness helps to improve incremental innovation in a company's performance. By analyzing the impact of both regional and inter-regional R&D cooperation on innovation performance, as well as the moderating role of technology diversification, Sun and Zang (2017) found that both regional R&D cooperation and inter-regional R&D cooperation have a significant positive impact on innovation performance. Regional cooperation helps more in expanding the scale of innovation, while inter-regional cooperation helps more in improving the quality of innovation. Technology diversification always has a significant negative moderator effect.

Negative impact

Costs are associated with implementing open innovation, including costs for knowledge search, coordination, and maintaining confidentiality. Open innovation will cause changes in company culture and organizational structure, inertia in the company's own R&D, leakage of key knowledge, and so on. This may cause the company to become dependent on network embeddedness and weaken its innovative capabilities (Ahuja and Lampert, 2001). In view of the negative impact of open innovation, an increase in openness will slow the development pace of new products and increase product development costs (Knudsen and Mortensen, 2011).

Nonlinear effects

A study by de Man and Duysters (2005) shows that the external cooperation of a company can have different effects on its innovation performance, including positive, negative, and neutral effects. Laursen and Salter (2006, 2014) analyzed the impact of openness on innovation performance and found that there is an "inverted U-shaped" relationship between openness and innovation performance. This finding has also been supported by research (Almirall and Casadesus-Masanell, 2010; Chiang and Hung, 2010). Chen and Chen (2008b) explored the effects of innovation openness on innovation performance in various industries and expanded the conclusions reached by Laursen and Salter (2006). Sofka and Grimpe (2010) pointed out that openness can encourage innovation performance, but companies must be careful about the direction of external search. Lichtenthaler, Hoegl, and Muethel (2011) indicated that the sale and purchase of technology with external entities can achieve the highest return in enterprise innovation – but that it is dangerous for a company to only focus on technology sales. According to the data from Italian manufacturing companies, Berchicci (2013) found that the use of external technology sources becomes detrimental to innovation performance beyond a particular value.

In accordance with the conclusion proposed by Laursen and Salter (2006), Greco, Grimaldi, and Cricelli (2016) analyzed the effects of openness depth and coupled OI on breakthrough

innovation and incremental innovation (on the basis of data from 84,919 companies in European innovation). The study shows that there is an “inverted U-shaped” relationship for the breadth of openness with breakthrough innovation and incremental innovation. The depth of open innovation does not have a weakening effect on breakthrough innovation. However, there is an inverted U-shaped relationship between the depth of open innovation and incremental innovation, which is not an obvious relationship. There is also an inverted U-shaped relationship between coupled OI and breakthrough innovation.

Given that the interaction between a company’s absorptive capacity and the openness of innovation has not been taken into account and the openness of innovation has not been matched to absorptive capacity, there are conflicts in existing empirical studies. With the same openness, the ability to acquire external knowledge is affected by absorptive capacity. Therefore, absorptive capacity is the key factor in determining the effect of open innovation.

Synergies between internal and external innovation resources in an open innovation environment

For innovation and development, a company should pay attention to the external environment and the integration of internal and external resources. The idea of promoting technological innovation with resources acquired externally has drawn the attention of numerous innovation management experts (Teece, 1986; Cohen and Levinthal, 1990; Mowery, Oxley, and Silverman, 1996; Hagedoorn, 1993, 2000; Brusoni, Prencipe, and Pavitt, 2001; Pavitt, 2002; Coombs, 2003; Powell and Grodal, 2005). Many researchers suggest that internal and external R&D are complementary. Internal R&D can improve a company’s capacity to absorb knowledge in the external environment (Cohen and Levinthal, 1990; Rosenberg, 1990). The acquisition and utilization of external knowledge is based on internal R&D capabilities, and the complementarity of internal and external knowledge enhances innovation performance (Teece, 1986; Arora and Gambardella, 1990; Cassiman and Veugelers, 2002; Belderbos, Prencipe, and Pavitt, 2004). Other researchers believe that internal and external R&D are negatively correlated (Basant and Fikkert, 1996; Fernandez-Bagües, 2004) and that there is a substitution effect between them. Finally, some researchers find no significant relationships between them.

What is the relationship between internal R&D and external knowledge search: Are they complementary synergies or alternatives? Does excessive external knowledge search weaken the strategic position of internal R&D and negatively affect the company’s sustainable competitive advantage? The key issue in this debate lies in the differences in absorptive capacities. A company must rely on its internal capability to effectively use external technologies. The balance between internal capabilities and the acquisition of external innovative resources has become a key issue. Therefore, it is important to understand the relationship between a company’s absorptive capacity and openness activities – and how a dynamic balance between internal and external innovation resources should be maintained. Interaction of the two types of resources enhances a company’s innovation performance.

The impact of internal R&D on open innovation

Lichtenthaler (2008a) holds that the internalization of external knowledge is required in open innovation – and that the external management capabilities such as absorptive capacity, learning ability, and dynamic capabilities are needed to retain, exploit, and develop interorganizational knowledge (Lichtenthaler, 2009a). Knowledge management capacities can be grouped into six categories: inventive, absorptive, transformative, connective, innovative, and desorptive

(Lichtenthaler and Lichtenthaler, 2009). From the perspective of absorptive capacity and process, Lichtenthaler also studied the learning process with technology and market knowledge (Lichtenthaler, 2008b). By strengthening cooperation with government, enterprises, industries, universities, research institutes, and public service platforms, the innovation performance of companies can be enhanced. Moreover, interactive learning plays an important role in the open learning process.

Internal R&D enhances the ability of a company to recognize, acquire, digest, and use external knowledge, that is, its absorptive capacity (Cohen and Levinthal, 1990). In a rich external knowledge environment, a company must identify and understand the abundance of external knowledge resources. It can then make selections by building links. Internal and external technologies should be integrated to create complex technology combinations, which further create new systems and frameworks (Chesbrough, 2003a). Absorptive capacity is a function of the company's prior knowledge and prior experience, which can be gradually accumulated through the company's R&D efforts (Cohen and Levinthal, 1989, 1990). The strength of a company's internal R&D capabilities determines its ability to recognize, digest, and use external knowledge. External knowledge and technological skills can be effectively used when a company has engaged in fundamental research and acquired sufficient internal R&D capabilities (Rosenberg, 1990; Cassiman, Perez-Castrillo, and Veugelers, 2002).

Positive effect of external knowledge search on internal R&D

For the effective use of external knowledge, companies with many external technology opportunities have strong incentives to increase investment in internal R&D. External knowledge search may therefore encourage, rather than substitute, internal R&D (Arora and Gambardella, 1990; Veugelers, 1997). In view of the complexity and interdisciplinary nature of technology, even large companies cannot keep up with the pace of development in all technologies (Veugelers, 1997). To encourage innovation, companies often need to use external knowledge to compensate for the lack of internal R&D. Therefore, external knowledge search increases the marginal return rate on internal R&D investment, which not only enhances innovation performance but also boosts the accumulation of internal technological capabilities.

Complementarity and synergy of internal and external knowledge

Gassmann (2006) proposed that companies should balance their ability to unearth internal knowledge resources and their ability to profit from external knowledge resources. Dahlander and Gann (2007) believe that the traditional path, structure, and culture of business innovation are the prerequisites for the identification, acquisition, and absorption of external knowledge.

There is complementariness between internal R&D and external knowledge search (Schneider, 2008; Hagedoorn and Ning, 2012; Chen and Ye, 2013; Sofka and Grimpe, 2010; Chen, Vanhaverbeke, and Du, 2016). The stronger a company's internal R&D capabilities, the more efficient is its external knowledge search. External knowledge search drives a company to enhance its internal R&D and improve the efficiency of its internal R&D.

External knowledge search has an important impact on the improvement of enterprise innovation performance, but different types of external cooperation objects differ in their importance to innovation performance. In business innovation practice, there is a complementary and synergistic relationship between internal R&D and knowledge search in vertical cooperative enterprises as well as horizontal enterprises. However, there is not enough evidence to show a complementary relationship between internal R&D and knowledge search by

universities or research institutes. Whether a relationship between internal R&D and external knowledge search is complementary or substitutive is primarily determined by a company's capacity to absorb external knowledge. If a company does not have enough absorptive capacity, its external knowledge search will become inefficient. The interactive relationship between internal R&D and external knowledge search explains why some companies can achieve a high efficiency in external knowledge search and achieve high rates of return on R&D investment.

The mechanism through which open innovation can affect innovation performance

Open innovation induces the free flow of innovative resources, which is an advantage. Open innovation mode provides companies with opportunities to obtain the various resources necessary for innovation, enhance their capabilities in technological innovation, and improve competitiveness. In open innovation, the various elements of innovation and means to acquire technologies influence and complement each other, and thus no innovation elements can be analyzed in isolation from the overall innovation strategy of the company. Why does openness enhance business innovation performance? What are the mechanisms by which the various innovation elements enhance innovation performance?

The mechanism that opens innovation and affects innovation performance has been researched from different perspectives, such as resources, knowledge, and capability.

The resource viewpoint

From the viewpoint of resources, Chen and Chen (2009) made an empirical analysis of the mechanism and action process of open innovation and found that open innovation enhances innovation performance through a process in which market information and technologies are acquired to compensate for the lack of internal R&D.

The knowledge viewpoint

Zheng, Ye, and Xu (2017) constructed a model that shows how the openness of clustered companies affects innovation performance based on the characteristics of the clusters. The research shows that innovation performance is affected by knowledge acquisition. A company's capacity to absorb knowledge affects the innovation performance formation process. The potential absorptive capacity plays a positive role in regulating the effect of openness on knowledge acquisition. The actual absorptive capacity plays a positive role in moderating the transformation from knowledge acquisition to innovation performance. Network centrality plays a positive role in regulating the effect of the breadth of openness in clustered companies on knowledge acquisition.

Jiang and Cai (2014) analyzed the open innovation of Refond Optoelectronics based on a case study and grounded-theory analysis. From the perspective of the point-edge-network of the alliance portfolio, the authors summed six structural characteristics or elements: resource diversity (quantity), resource heterogeneity (quality), breadth of openness (quantity), depth of openness (quality), structural strength, and a coupling mechanism on the three levels of the alliance portfolio – company (point), relationship (edge), and network (network). The authors also examined the mechanism by which the six structural characteristics encourage open innovation performance through enhanced knowledge flow, absorption, transfer, and creation. In the future,

comparative studies can be made with large cases and empirical studies can be made to verify the action mechanism by which the structural characteristics of the innovation network affect the performance of open innovation.

The capability viewpoint

Yao, Ouyang, and Zhou (2017) studied the mechanism by which open innovation affects enterprise competitiveness from the internal ability and external environment. Based on the empirical data of 271 Chinese companies, the finding shows that open innovation (including inbound and outbound) positively affects enterprise competitiveness. The dynamic capability of knowledge is the full mediation between open innovation and enterprise competitiveness. Partner opportunism negatively moderates the effects of both inbound and outbound open innovation on enterprise competitiveness.

Based on the action process of open innovation, Zhu and Hao (2014) further divided the technological innovation capability of enterprises into three subcapabilities – absorptive capability, integration capability, and original capability. The authors then proposed the pool-pump mechanism by which enterprise technological capability increases cyclically in an open innovation environment. Combined with the case study on the Neusoft Group, the research analyzed the capability of a company to produce endogenous new knowledge through absorbing and integrating external knowledge and resources in an open innovation environment.

Lv, Shi, and Ji (2017) took the smartphone industry as the research object from the embeddedness perspective of innovation networks and explored the effect of the openness of a company's open innovation process on its ability to achieve incremental innovation. Their research shows that innovation process openness indirectly affects the incremental innovation capability by moderating the interaction between the level of innovation network embeddedness and the capability to achieve incremental innovation. In the preliminary stage of technology development in an industry, innovation process openness positively moderates the effect of innovation network embedding on the incremental innovation capability. In an emerging stage of technology development in an industry, the moderating effect of innovation openness ceases to exist. In the stable stage of technology development in the industry, only the breadth of innovation openness positively moderates the effect of innovation network embeddedness on incremental innovation capability.

Yan and Cai (2014) studied the effect of innovation openness on innovation performance. Innovation openness first affects a company's innovation orientation (exploration-based innovation and development-based innovation) and then affects innovation performance. The innovation orientation and business model act as mediators between innovation openness and innovation performance.

Organizational implementation of open innovation

The implementation of open innovation does not happen automatically. External innovation resources do not flow into companies, and implementations of open innovation in different companies produce different results. Open innovation highlights the entire innovation system. For companies of different characteristics and at different stages of the R&D process, decisions about the openness degree may be different, and this is related to the company's absorptive capacity, choice of cooperation objects, and organizational form. Where should a company search for external knowledge? How do they make best use of open innovation?

Christensen, Olesen, and Kjaer (2005) point out that the dynamic characteristics in open innovation and the mode of open innovation management are related to the company's position and the maturity of the technology. On the basis of the U-A model, Chen and Chen (2009) analyzed the key innovation factors for companies in different industries and stages of technological innovation and constructed the dynamic model of open innovation. Chiaroni, Chiesa, and Fratini (2010, 2011) summarized the changes of the organizational structure and management system from the closed to open state. Bianchi et al. (2011) explored the selections of organizational structure and cooperation partners in open innovation by studying biopharmaceutical industries at different stages of drug discovery and development.

Makri, Michael, and Peter (2010) found that dispersed distribution of knowledge and information affects the search strategy in innovation activities. Argote and Greve (2007) believed that diverse external resources could facilitate innovation. Selective knowledge sharing by customers, competitors, and suppliers could enhance a company's innovative capabilities according to von Hippel and von Krogh (2003, 2006). However, constraints on resource consumption are related to the depth of search. A deep search of external knowledge sources is a resource-consuming process and difficult to implement under strict constraints (Ferru, 2010).

What determines the selection of an open innovation model in companies? For innovation activities, different R&D objects at different stages of the innovation process have different investment needs and risk tolerance. Thus, the innovation mode adopted is closely related to the stage of innovation of the "innovation object" – including technology, product, service, etc. (Laursen and Salter, 2006). The mode is also related to whether an organization constantly makes adjustments to its innovative behaviors to adapt to the needs of different innovation objects at different stages (Chesbrough, Vanhaverbeke, and West, 2006). For organizations with diverse technologies (products or services and so on), adopting different modes of open innovation may be a problem.

In the practice of innovation, there are a number of organizational models for innovation that take different external organizations as the main aims of openness – and different models of innovation have different effects on innovation performance. Walsh, Lee, and Nagaoka (2016) analyzed the impact of cooperation with heterogeneous entities on innovation performance at different stages of the innovation process. The empirical studies show that the cooperation with industries, universities, and research institutes helps improve the quality of the invention or patent at the invention stage. And vertical cooperation with customers and suppliers helps improve the success rate of the commercialization of the invention at the implementation stage. There are interactions between a company's internal capabilities and its mode of openness. Companies should choose the mode of openness that matches their internal capabilities. Companies with strong internal R&D capabilities can improve their innovation performance through cooperation with partners in science. Those with strong internal R&D capabilities but average manufacturing capabilities should seek cooperation with other horizontal companies. Those with average levels of internal R&D capabilities can markedly improve their innovation performance through close cooperation with organizations that are technologically strong and partners on the value chain. Enterprises should not blindly open to external organizations. The core issue in selecting the right target of openness is whether or not the company can obtain complementary resources that benefit the innovation effort.

From the point of the microscopic view of R&D entities, Sun, Wang, Ding, and Wei (2016) studied the selection of factors in the open innovation mode. Cases on China's DEEJ, Inc., and Japan's Sankyu, Inc., showed that there can be multiple modes of open innovation in the same business organization, which is closely related to the core competency corresponding to the innovation object. And the selection of innovation modes is the manifestation of the

dynamic shifts in the related core competencies. Organizational core competencies include the competency fulcrum and competency periphery. The core competency periphery is further divided into the exclusive capability periphery and cluster capability periphery. The core competences correspond to a specific innovation mode. The depth of innovation mode and the breadth of innovation mode may be suitable for an exclusive capability periphery (with high entry barriers of entry) and for a cluster capability periphery (with low entry barriers of entry), respectively.

Management implications of open innovation

Open innovation emphasizes the importance of external knowledge sources to innovation. It differs from the traditional closed innovation model that emphasizes vertical integration and strict internal control, differs from imitative innovation that is based on the introduction of external technology, and differs from general cooperative innovation. In the open innovation mode, a company conducts an external search and acquires and uses innovation resources. Through win-win synergistic cooperation and integration of internal and external resources, the commercial value gained from R&D investment can be maximized.

The open innovation model has changed the way in which companies obtain innovative resources. Company boundaries are permeable in the open innovation mode. A company cannot only use its own resources, but must use innovative resources from the external environment, such as users, suppliers, competitors, other companies, universities, research institutes, technology intermediaries, government, trade associations, periodicals, seminars, media, and so on. These are all important sources of technology, knowledge, and other innovative resources for companies.

In the open innovation paradigm, external knowledge sources are crucial, regardless of the level of an innovative entity: state, industry, or enterprise (Cohen and Levinthal, 1990). Therefore, the development and use of external knowledge is an important component of a company's innovative capability and external experience – and ideas are considered to be important tools for corporate learning (Jerez-Gómez, Céspedes-Lorente, and Valle-Cabrera, 2005). Many multinationals continuously establish knowledge absorption centers in different regions around the globe so as to strengthen global search in their respective research areas and technology fields. Learning by imitation, interaction, and spillovers of industry competition are important ways to encourage innovation. The process by which a company follows what other companies are doing in a particular area and adopts the useful technologies or practices can improve its capability in learning technologies.

In an open innovation environment, the internal R&D of a company still plays an important role, but the function has changed. The acquisition of external innovative resources is very important for enhancing the company's innovation performance, but internal innovation resources are still the most essential and critical innovation element. External innovative resources supplement internal innovation resources but can substitute for them. Open innovation does not negate internal innovation. Instead, it could make full use of internal and external knowledge and resources and construct an innovation ecosystem that maximizes R&D efficiency.

In the open innovation environment, the various elements of innovation and various means to acquire technology influence and complement each other, and no innovation elements can be analyzed in isolation from the overall innovation strategy of the company. Therefore, in the practice of innovation, a company must seek to match and integrate internal and external resources based on its internal resources and absorptive capacity. A suitable innovation strategy

should be adopted to maximize the synergy of its internal and external innovative resources and enhance its innovative capabilities. To improve innovation performance and enhance innovation capabilities, companies need to simultaneously strengthen internal R&D activities and external knowledge search.

The abundance of external innovative resources adds to the complexity of enterprise innovation management. When a company is accumulating and nurturing internal technological capabilities, it also needs to make use of external resources and improve its innovation performance by integrating its internal and external resources. Given that partners in an innovation effort are not independent, the various elements of innovation and the various means to acquire technologies influence and complement each other, so no innovation elements can be analyzed in isolation from the overall innovation strategy of a company.

Implications of open innovation for business management practice

Implications of open innovation on management practice are mainly related to the interaction between a company and external organizations and the utilization of external innovative resources.

In the practice of innovation, companies acquire complementary innovation resources and encourage innovation through purposefully open interaction with such external organizations

It is not advisable to put open innovation capabilities on developing core technologies that are achieving technological breakthroughs. For innovation and development, enterprises should pay more attention to the external environment and the acquisition and utilization of external resources. The technological innovation modes of most companies in China are relatively closed, the utilization rates of external resources are limited, and R&D capabilities are dispersed, and this results in inefficiency in the innovation process. Open innovation can gather the creative ideas and accelerate the pace of innovation to better use market opportunities.

Business leaders must pay close attention to the construction of the innovation ecosystem, and change the closed mode of internal R&D to an open one, and effectively integrate creativity management, R&D management, manufacturing management, and marketing management systems. R&D efficiency is in this way maximized in an environment of rich external technology resources and free knowledge flows.

External knowledge search has an important impact on the improvement of enterprise innovation performance, but different types of external cooperation objects differ in their importance to innovation performance

For Chinese companies, knowledge acquisition from companies in vertical relationships currently has the greatest effect on enhancing innovation performance. Cooperation with companies in horizontal relationships shows the least effect on enhancing innovation performance, and universities, as well as research institutes, play important roles in innovation practices. To encourage innovation, companies in technology-driven industries need to selectively build cooperative relationships with a small number of external sources of innovation. Companies in experience-driven industries should form effective links with external organizations to encourage innovation.

Internal and external R&D innovation strategies complement each other, but the degree of complementarity is influenced by the choice of external search object and a company's capacity to absorb external knowledge

Close connections between a company and external organizations help improve a company's innovation performance, and a company's internal R&D plays an important moderating role. The company's internal resources and the search for external innovative resources are significantly complementary to each other, and the intensity of internal R&D activities determines the degree of influence exerted by its external knowledge search on its innovation performance. If a company does not have enough absorptive capacity, its external knowledge search will become inefficient. In the practice of innovation, a company must seek to match and integrate its internal and external resources. On the basis of its internal resources and absorptive capacity, a suitable innovation strategy should be adopted to maximize the synergy of its internal and external innovative resources and enhance its innovative capabilities. To improve innovation performance and enhance innovation capabilities, companies need to strengthen their internal R&D activities and external knowledge search simultaneously.

In the practice of open innovation, a number of organizational modes of open innovation take a particular cooperation object as the main target of the openness. Different modes of openness have different effects on innovation performance, and there is an interactive relationship between a company's internal capabilities and the mode of openness it adopts.

In practice, there are four types of organizational modes of innovation with a particular cooperation object as the main target of openness: partners in scientific endeavors, partners in the value chain, companies with horizontal cooperation, and organizations in related technology fields. Different organizational modes of innovation are significantly different in their effects on innovation performance. There is an interactive relationship between a company's internal R&D capabilities and the organizational mode of openness. A company with a given set of characteristics should choose a mode of openness that matches its internal capabilities. Companies with strong internal R&D capabilities can improve their innovation performance through cooperation with scientific partners. Those with strong internal R&D capabilities but average manufacturing capabilities should seek horizontal cooperation with other companies. Those with average internal R&D capabilities can markedly improve their innovation performance by close cooperation with organizations in related technologies and partners on the same value chain. Enterprises should not open themselves to external organizations blindly. The key issue in selecting the right targets of openness is whether the company can obtain complementary resources from the innovation.

In the practice of open innovation, internal R&D and innovation of enterprises become more important and internal R&D capabilities are still the key roles

Open innovation is not a model in which external innovative resources are simply required for innovation. Adopting open innovation does not imply abandoning internal R&D and innovation. Faced with an abundance of external knowledge sources, companies need to be engaged in internal R&D activities to identify, understand, select, and connect to external knowledge sources. Companies can then fill in the gaps in knowledge areas that have not been developed

externally, integrate internal and external knowledge to form knowledge combinations of greater complexity, create new systems and architectures, and gain extra revenues and profits from the fruits of their own research being used by other companies (Chesbrough, 2003b). In an environment of open innovation, enterprise internal R&D and innovation hold even greater significance for developing countries. It is the ongoing investment in internal R&D that enables companies to efficiently integrate internal and external innovation resources in an internationalized open innovation setting and achieve maximum synergy between internal and external innovation resources.

An innovative company must develop a good organizational mechanism to encourage the effective implementation of open innovation

Open innovation is not an occasional or accidental event for companies. It is a regular and essential activity built on the foundation of the company's business culture, organizational structure, and processes. A good mechanism of open innovation must be developed to ensure that external innovative resources are fully utilized for the improvement of the integrity, continuity, and efficiency of the innovation process, which will enhance the company's innovation performance and sustained competitiveness.

Reaching open innovation maturity in a business

A considerable number of open innovation projects in companies fail because the management firms are not ready to fully engage in open innovation. As we mentioned already, open innovation has to be managed carefully, and most firms lack knowledge about how to manage it. The development of open innovation maturity – that is, an organization's excellence in conducting open innovation – is a slow process taking many years. An analysis of open innovation maturity shows how firms can get onto higher maturity levels over time. In other words, open innovation maturity describes firms' overall capacity to successfully engage in and make use of open innovation.

Enkel, Bell, and Hogenkamp (2011) have developed a detailed framework for open innovation maturity that allows measuring the effectiveness of open innovation processes. They argue that the effectiveness of firms' open innovation activities is a function of their partnership capacity (Cullen, Johnson, and Sakano, 2000; Kauser and Shaw, 2002; Mora-Valentin, Montoro-Sanchez, and Guerras-Martin, 2004; Lichtenthaler and Lichtenthaler, 2009; Cohen and Levinthal, 1990). Also the creation of a climate that is conducive to innovation and visionary leadership is essential for (open) innovation activities (Tidd and Bessant, 2009; Anderson and West, 1998; Thamhain, 2003). Finally, the availability of the right systems, tools, and processes is an important enabler for open innovation initiatives (Thamhain, 2003; Dilk et al., 2008; Kauser and Shaw, 2002; Ireland, Hitt, and Vaidyanath, 2002).

These three elements of open innovation – climate for innovation, partnership capacity, and internal processes – are the three dimensions in which companies have to make change over time to become mature in open innovation management. Climate for change is operationalized into variables such as clear strategy, incentives, and mind-set. Partnership capacity is about reputation, partner selection, and training and education. Finally, internal processes can be split up into central coordination, resources, knowledge management process, and the legal and IP systems.

Based on the analysis of five cases Enkel, Bell, and Hogenkamp (2011) make a distinction between five stages of open innovation maturity: initial/arbitrary, repeatable, defined, managed, and optimized. As firms make progress and shift from lower to higher stages of open innovation

maturity, the approach becomes more detailed at each phase and the progress is based on the accumulated experiences of companies over time in dealing with open innovation. The major managerial contribution of their publication lies in the translation of the concept of open innovation maturity into an easy-to-use Excel tool leading to a spider web graph that visualizes the companies' open innovation maturity against a benchmark.

Analysis and recommendations of open innovation policy

Improving the capabilities of independent innovation and gaining the capabilities of key technology development is a complex and lengthy process that includes a long period of technology accumulation and investment. China has reached an advanced international level in some technology areas but is still some distance behind the developed nations. In an environment of open innovation, it is not advisable to place all the effort for strengthening innovative capabilities on developing core technologies and seeking breakthroughs. In an era of economic globalization and rapid technological development, maintaining and continuously strengthening our competitive advantages and improving independent innovation depends on our ability to create, apply, share, and accumulate knowledge. It also depends on our ability to acquire and use global knowledge and technologies, and our ability to effectively integrate technological resources globally.

Strive to improve the scientific competencies and learning abilities of our people

Technological innovation emphasizes the integration of research and industry chains. Strengthening self-dependent innovation capabilities is not just a task for science and technology talents: the practice of innovation is a basic duty of every member of society. The key to enhancing the capabilities of independent innovation is by improving the scientific skills and learning abilities of our people. In an open innovation environment, it is the ability to acquire knowledge, rather than the amount of knowledge possessed, that determines innovation performance. Lundvall (2017) pointed out that the key to achieving good economic performance is promoting learning at every stage of the economic system. Only with organizational changes and the broad elevation of employee skills can the introduction of advanced technologies play a positive role. The mere application of technology in the search for solutions to problems is destined to fail.

In an environment of open innovation, the key to strengthening innovative capabilities is the ability to acquire and use knowledge and technologies globally, as well as the ability to integrate technology resources globally. Learning ability is an important foundation for enhancing the capability to absorb external knowledge and integrate internal and external knowledge. To improve independent innovation capabilities in China, we must build a learning society and nurture and elevate the learning ability and innovation awareness of our people. We must provide lifelong education to the general public so that people can learn technological ideas, knowledge, methods, and skills, and so further strengthen their ability to understand, master, and apply modern science and technology. Finally, if scientific thinking and concepts are embedded into our national spirit, then our innovation capabilities will build an innovative nation.

Strengthen the construction of knowledge infrastructure and encourage the dissemination and sharing of knowledge

Independent innovation in an open environment emphasizes the integration and consolidation of multiple innovation elements, for which the transfer and sharing of knowledge play an

important role. The ability to efficiently acquire and use innovation resources globally is the key ability for achieving technological innovation. In the process of knowledge dissemination, sharing, and utilization, information and communication technologies serve as the foundation for the free flow of information. Among the many factors that limit our ability to innovate, a failure to build the knowledge infrastructure and a lack of knowledge resources are significant. According to global statistics, investment by advanced companies in knowledge resource acquisition, knowledge management, and other elements related to building knowledge infrastructure account for nearly 10 percent of overall R&D investment. Investment is above 25 percent for the leading firms. In contrast, investment by Chinese companies is only 0.5 percent. We should elevate knowledge resources to the level of strategic national resources by strengthening the construction of nationwide and regional information and communication systems and other knowledge infrastructure projects. Moreover, we must provide companies and people with a learning platform for public knowledge, achieve effective integration among research entities and technology resources, effectively integrate and use global technology resources, and enhance our capabilities of independent innovation.

Encourage companies to increase investment in R&D and improve absorptive capacity and resource integration

In an open innovation environment, the ability to acquire, absorb, and use external knowledge and effectively integrate internal and external innovative resources is the key to improving technological innovation. However, successful implementation of open innovation in our country still requires that our companies have strong R&D capabilities. Such capabilities are the foundation for developing new products with independent intellectual property rights and serve as the essential guarantee for improving external knowledge search, acquisition, and absorption. China's fiscal investment in science and technology currently accounts for a substantial percentage of R&D investment. Encouraging companies to increase their R&D investment is particularly important for guiding R&D investment in our society. The government should adopt the fiscal and financial measures for an active government procurement system that encourages innovation activities and increases R&D investment by enterprises. The government should also provide clear policy guidance and create a favorable macro- and micro-economic environment for enterprise innovation activities.

Give priority to the construction of innovation platforms for industrial technologies and encourage information exchange and technology transfer

The government should provide companies engaged in independent R&D activities with a policy support environment that is conducive to innovation by enacting appropriate laws and regulations. The government should organize and coordinate the construction of platforms for generic technology innovation, perfect the environment for the cooperative development of generic technologies, ensure the rapid transformation of generic technologies, play a role in the development and diffusion of generic technologies, and encourage the advancement of generic technologies. Government agencies should formulate policies optimizing the environment; improve the social support system; build a platform for technology exchange that is conducive to information flow and information transfer; and construct an effective enterprise technology innovation service that can provide services in areas such as information, talent, financing, technology, and management consulting. The government can then encourage technology and information exchange between companies and research institutes or among companies. By

giving full play to the interaction between government and companies, a synergy of market mechanism and government support can improve the efficiency of the national innovation system.

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