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Effects of absorptive capacity, trust and information systems on product innovation

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Abstract

Purpose – The purpose of this paper is to empirically investigate the mechanisms through which absorptive capacity (AC), trust and information systems jointly influence product innovation.

Design/methodology/approach – This study proposes a research model to examine the mediating role of AC on the impacts of trust and information systems on product innovation and the moderating roles of trust and information systems on the relationship between AC and product innovation. The hypotheses are empirically tested using regression and bootstrapping methods and data collected from 276 manufacturing firms in China.

Findings – This study finds that trust and information systems positively affect product innovation and the effects are fully mediated by AC. AC also significantly enhances product innovation, and the effect is amplified by trust as well as information systems. In addition, the results show that trust and information systems improve AC both individually and interactively.

Originality/value – The findings extend existing knowledge on the antecedents of AC and the contingent conditions under which a manufacturer's AC is more effective than that of its rivals. The results also clarify the mechanisms through which trust and information systems improve product innovation. This study provides insights into the complex relationships among a manufacturer's sociotechnical systems, knowledge management processes and new product development, and reveals how to design organisational systems to fully capitalise the value of AC on product innovation.

Keywords Trust, Product innovation, Information systems, Absorptive capacity

Paper type Research paper

1. Introduction

Absorptive capacity (AC) serves as an important component of a manufacturer's learning capabilities by creating a set of organisational routines and processes (Cohen and Levinthal, 1990; Zahra and George, 2002). It can help a manufacturer develop new knowledge as well as adapt existing knowledge into new applications (Lane *et al.*, 2006; Lawson and Potter, 2012; Nagati and Rebolledo, 2012; Whitehead *et al.*, 2016). Researchers report that AC is positively associated with a manufacturer's performance and capabilities (Tu *et al.*, 2006; Francalanci and Morabito, 2008; Kauppi *et al.*, 2013; Tavani *et al.*, 2014; Iyengar *et al.*, 2015), including product innovation (Cepeda-Carrion *et al.*, 2012; Ritala and Hurmelinna-Laukkanen, 2013; Saenz *et al.*, 2014). Both mediation (Francalanci and Morabito, 2008; Cepeda-Carrion *et al.*, 2012; Setia and Patel, 2013; Saenz *et al.*, 2014; Iyengar *et al.*, 2015) and moderation (Patel *et al.*, 2012; Kauppi *et al.*, 2013; Ritala and Hurmelinna-Laukkanen, 2013; Tavani *et al.*, 2014) models have been used to empirically investigate the relationships between AC and performance outcomes. However, the contingent conditions that influence AC's effect on product innovation have been overlooked in previous research.

The sociotechnical systems theory proposes that a firm is composed of both social and technical systems (Pasmore, 1988). They should be treated as interdependent aspects of an

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organisation and be jointly designed according to internal and external environments (Pasmore, 1988; Huber and Brown, 1991). Trust and information systems reflect the social and technical aspects of an organisational system (Mayer *et al.*, 1995; Alavi and Leidner, 2001). An organisational design that only considers one of the two aspects will be inefficient for knowledge absorption and product innovation (Huber and Brown, 1991; Lane *et al.*, 2006). In addition, a knowledge-based view of the firm argues that firms can gain competitive advantages by combining and creating tacit and explicit knowledge and they have different properties and require different mechanisms for absorption (Nonaka, 1994; Zhang *et al.*, 2015). Trust and information systems provide two mechanisms governing the flows and applications of tacit and explicit knowledge, respectively (Malhotra *et al.*, 2005; Nahapiet and Ghoshal, 1998; Roberts *et al.*, 2012). Trust enables employees to access each other's private experiences and build a social system for them to share know-how, facilitating the socialisation and externalisation of tacit knowledge (Nonaka, 1994). Trust also motivates cooperative behaviour and reduces opportunism in cross-functional collaboration, which promotes joint learning (Yeung *et al.*, 2009; Zahra and George, 2002). Information systems facilitate a firm to analyse, distribute and record large amount of information quickly and efficiently, and hence provide a technical system to combine and internalise explicit knowledge (Nonaka, 1994; Setia and Patel, 2013).

Researchers argue that social integration mechanisms can build connectedness and shared meaning among employees which facilitate the free flow of knowledge (Zahra and George, 2002; Todorova and Durisin, 2007) and that the synergies between information technologies and AC affect firm performance (Roberts *et al.*, 2012). However, there is a lack of explanation of how trust and information systems jointly affect knowledge absorption and how they influence the effects of AC remains underaddressed (Hotho *et al.*, 2012; Marabelli and Newell, 2014; Iyengar *et al.*, 2015). In addition, Volberda *et al.* (2010) argue that organisational design has been relatively neglected in the AC literature. Moreover, few if any researchers have linked AC to the effects of trust and information systems on product innovation (Cepeda-Carrion *et al.*, 2012; Setia and Patel, 2013).

The objective of this study is to empirically investigate the mechanisms through which AC, trust and information systems jointly influence product innovation. This study addresses two research questions:

RQ1. Does AC mediate trust and information systems' effects on product innovation?

RQ2. Do trust and information systems moderate AC's effect on product innovation?

2. Theoretical background and research hypotheses

2.1 AC

AC can be defined as a firm's "ability to recognize the value of new information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128). Researchers argue that AC is a multiple-dimensional concept and the components are interrelated (Zahra and George, 2002; Zhang *et al.*, 2015). Research and development (R&D) intensity, R&D investment and patent have been used as proxies for measuring a firm's AC. However, such proxies are unidimensional measures that are not able to fully gauge this multi-dimensional construct (Roberts *et al.*, 2012; Volberda *et al.*, 2010) and cannot capture a firm's learning processes (Setia and Patel, 2013). In addition, they only focus on technological knowledge, whereas neglect or undervalue market knowledge (Lane *et al.*, 2006; Ritala and Hurmelinna-Laukkanen, 2013). With a few exceptions (e.g. Patel *et al.*, 2012; Saenz *et al.*, 2014; Zhang *et al.*, 2015), empirical operations management studies measure AC using prior-related knowledge and communication routines (Tu *et al.*, 2006; Nagati and Rebolledo, 2012; Kauppi *et al.*, 2013; Tavani *et al.*, 2014) or general scales related to organisational learning (Zacharia *et al.*, 2011; Whitehead *et al.*, 2016). However, they neither directly capture a firm's capability to implement and apply knowledge (Lane *et al.*, 2006; Roberts *et al.*, 2012) nor reflect the richness of the construct (Volberda *et al.*, 2010).

This study conceptualises AC as three components (i.e. acquisition, assimilation and application) that are necessary for a manufacturer to absorb knowledge from supply chains (Nagati and Rebolledo, 2012; Zhang *et al.*, 2015). Acquisition refers to a manufacturer's ability to identify and obtain knowledge that is critical to its operations from suppliers and customers (Hult *et al.*, 2004; Todorova and Durisin, 2007). Suppliers and customers are important sources of technological and market knowledge, such as new product concepts, local customers' special demands and new applications of materials (Hult *et al.*, 2006). A manufacturer can acquire knowledge from supply chain partners through special procedures and interactions, such as meetings or surveys (Hult *et al.*, 2004). Assimilation refers to a manufacturer's processes and routines for analysing, interpreting and understanding externally acquired knowledge and combining it with internal knowledge (Zahra and George, 2002). Various practices, such as group learning, collaborative problem solving, knowledge sharing routines and training programmes, can be used to assimilate knowledge (Hult *et al.*, 2004; Jansen *et al.*, 2005). Application refers to the processes through which a manufacturer exploits knowledge to improve and expand its daily operations, create commercial outputs and predict future trends (Lane *et al.*, 2006; Zahra and George, 2002). A manufacturer can apply knowledge by implementing employees' suggestions and ideas and reviewing long-term forecasting to discover business opportunities (Volberda *et al.*, 2010). Hence, such conceptualisation provides a thorough assessment of both external-facing and internal components of AC (Todorova and Durisin, 2007; Roberts *et al.*, 2012; Zhang *et al.* 2015).

Researchers find that AC positively influences knowledge transfer (Lawson and Potter, 2012; Whitehead *et al.*, 2016), innovation (Cepeda-Carrion *et al.*, 2012; Ritala and Hurmelinna-Laukkanen, 2013), manufacturing capabilities (Tu *et al.*, 2006; Zhang *et al.*, 2015) and business performance (Francalanci and Morabito, 2008; Nagati and Rebolledo, 2012). In addition, empirical evidence exists that AC mediates the relationships between information systems and business performance (Francalanci and Morabito, 2008; Liu *et al.*, 2013; Setia and Patel, 2013; Iyengar *et al.*, 2015) and between organisational compatibility and innovation (Saenz *et al.*, 2014). Researchers also report that AC positively moderates the relationships between manufacturing flexibility and firm performance (Patel *et al.*, 2012), between E-purchasing tools and category performance (Kauppi *et al.*, 2013) and between supplier involvement and agile product innovation (Tavani *et al.*, 2014), and that the effect of AC is moderated by environmental conditions such as complexity (Setia and Patel, 2013), uncertainty (Saenz *et al.*, 2014) and appropriability regime (Ritala and Hurmelinna-Laukkanen, 2013). However, there is a lack of empirical studies on how AC interacts with a manufacturer's organisational system in influencing product innovation.

2.2 Product innovation

Product innovation refers to the new applications of knowledge and skills that can change what a manufacturer offers to customers (Kim *et al.*, 2012). A manufacturer can develop incremental or radical product innovations, which are different in the degree of newness as perceived by customers (Damanpour, 2010; Ritala and Hurmelinna-Laukkanen, 2013). Radical innovations fundamentally change a manufacturer's technological trajectory and target emerging customers, whereas incremental innovations result in small changes in a manufacturer's technological capabilities and address existing customer needs (Kim *et al.*, 2012; Enkel *et al.*, 2017). Hence, radical and incremental innovations are associated with exploratory and exploitative learning, respectively (Enkel *et al.*, 2017). Exploration involves a conscious effort to move away from current organisational routines and knowledge bases, whereas exploitation focusses on using the knowledge that is closely related to firms' existing knowledge bases (Katila and Ahuja, 2002). New product development is determined by the combination of exploration and exploitation (Katila and Ahuja, 2002). Manufacturers can create new products by integrating existing knowledge and adapting existing products and technologies innovatively to fit new environments (Hargadon and Sutton, 1997). New products can also be developed by using new components or modules that overturn the core design concepts of current products (Hargadon and Sutton, 2000). Product innovation requires manufacturers to identify potential new markets and valuable business opportunities, recognise and obtain new technological and market knowledge from environments and transform and integrate such knowledge into internal operations quickly (Hult *et al.*, 2004; Whitehead *et al.*, 2016). Hence, manufacturers' capabilities to absorb and leverage both codified explicit and experience-based tacit knowledge, some of which may reside in supply chains, play a critical role in new product development (Hargadon and Sutton, 1997; Wang *et al.*, 2011). AC enables a manufacturer to conduct exploratory and exploitative learning simultaneously (Marabelli and Newell, 2014; Enkel *et al.*, 2017). In particular, acquisition allows a manufacturer to recognise and obtain valuable knowledge from supply chains through exploratory learning, and application enables the manufacturer to use assimilated knowledge to create new knowledge and commercial outputs through exploitative learning (Lane *et al.*, 2006). Hence, AC can affect both radical and incremental innovation (Ritala and Hurmelinna-Laukkanen, 2013; Enkel *et al.*, 2017). In addition, researchers argue that product innovation may be influenced by a manufacturer's demographic characteristics such as size and industry (Damanpour, 2010; Mazzola, Perrone, and Kamuriwo, 2015) and R&D collaboration with external partners (Hargadon and Sutton, 2000; Un *et al.*, 2010; Lawson and Potter, 2012; Mazzola, Bruccoleri, and Perrone, 2015; Wang *et al.*, 2011).

2.3 Trust and information systems

Trust can be defined as the "willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" (Mayer *et al.*, 1995, p. 712). This study focusses on the trust among employees in marketing, production and R&D departments as it facilitates social interactions within a manufacturer (Hotho *et al.*, 2012). High levels of trust indicate that both "teacher" and "student" are reliable, benevolent and honest (Mayer *et al.*, 1995). Trust encourages the "teacher" to actively help the "student" understand the knowledge he/she is offering. The "student" will also have a positive expectation of the "teacher", which increases the willingness of the "student" to absorb knowledge (Mayer *et al.*, 1995; Nahapiet and Ghoshal, 1998). Trust thus creates a sense of security among employees that their knowledge will not be exploited by colleagues beyond what is intended. It provides a social system that is critical for tacit knowledge transfer and creation (Wang *et al.*, 2011). The collaboration among marketing, production and R&D departments plays a critical role in new product development (Calantone *et al.*, 2002; Swink and Song, 2007). Employees in different functions may have diverse perspectives and motivations and different experiences and backgrounds, which may become barriers for cross-functional product development (Swink and Song, 2007). Trust among R&D, production and marketing departments cannot only lead to a working environment with open communication and team spirit, but also generate reciprocity and solidarity, which reduce the costs and lead times for collaborative knowledge management and innovation (Adler and Kwon, 2002).

Information systems offer effective tools for employees to scan environments and manage knowledge (Alavi and Leidner, 2001; Tu *et al.*, 2006). By using common specifications or formats for information exchange and knowledge transfer, information systems help a manufacturer collect codified facts from environments quickly with low costs (Tavani *et al.*, 2014). They assist a manufacturer in analysing and assigning meaning to obtained information (Malhotra *et al.*, 2005). Information systems also automate and routinise information assimilation, distribution and storage, which improve a manufacturer's information processing capability (Alavi and Leidner, 2001; Francalanci and Morabito, 2008). They can link internal and external sources of information to improve the breadth and depth of information flows and provide effective search and retrieval mechanisms for locating relevant information (Liu *et al.*, 2013). As a result, information systems form a technical system that facilitates knowledge absorption, especially for explicit knowledge (Malhotra *et al.*, 2005; Setia and Patel, 2013). Current knowledge on how information systems and AC jointly affect performance remains unclear (Liu *et al.*, 2013; Iyengar *et al.*, 2015). For example, empirical evidence exists that information systems mediate (Cepeda-Carrion *et al.*, 2012) or moderate (Setia and Patel, 2013) the relationships between AC components, and that AC mediates (Francalanci and Morabito, 2008; Liu *et al.*, 2013; Iyengar *et al.*, 2015) or moderates (Kauppi *et al.*, 2013) the impacts of information systems on performance.

2.4 Research hypotheses

Knowledge is a strategic resource and the capabilities in knowledge absorption and development have persisting effects on innovation (Hult *et al.*, 2006; Lane *et al.*, 2006). Trust among employees enhances product innovation by facilitating cooperation and collaboration among marketing, production and R&D departments (Swink and Song, 2007). Information systems provide a platform and tools that facilitate employees to process information and make decisions related to new product development quickly (Liu *et al.*, 2013). It is the new knowledge and new applications of existing knowledge developed through cross-functional collaboration and by using information systems that lead to product innovation (Nonaka, 1994; Nahapiet and Ghoshal, 1998). Hence, this study argues that AC, which enables a manufacturer to acquire and implement knowledge, mediates the effects of trust and information systems on product innovation. In addition, explicit knowledge can be transferred and exploited using systematic and standard procedures and tools, whereas the sharing and implementation of tacit knowledge requires social interactions and relationships among employees (Nonaka, 1994). Hence, this study argues that trust and information systems can form sociotechnical systems that positively moderate AC's effect on new product development. Because the interactions between tacit and explicit knowledge improve knowledge creation capability (Nonaka, 1994), we propose that trust and information systems are complementary in improving AC. The proposed conceptual framework is presented in Figure 1.

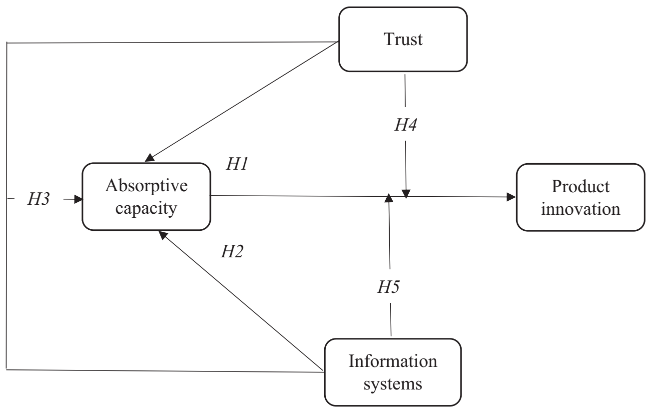

Figure 1.
Conceptual framework

Manufacturers can create new products by brokering external knowledge and developing new applications of existing knowledge (Hargadon and Sutton, 2000; Zhang *et al.*, 2016). R&D employees must work together with marketing and production employees who can provide knowledge about customer preferences and production processes to guarantee the marketability and manufacturability of new product designs (Swink and Song, 2007). High levels of trust indicate that employees have beliefs in the good intention, reliability and openness among each other (Nahapiet and Ghoshal, 1998; Adler and Kwon, 2002). Hence, trust among marketing, production and R&D employees can facilitate cross-functional product development (Calantone *et al.*, 2002). Employees can hence grasp what changes on product concepts, components and linkages between them really matter for customers and understand the capacity and capability of the manufacturing processes, improving product innovation (Calantone *et al.*, 2002; Kim *et al.*, 2012).

Trust increases employees' confidence about colleagues' goodwill and their willingness for participating in social interactions, which lead to common understandings among employees (Adler and Kwon, 2002; Mayer *et al.*, 1995). Hence, trust improves the quality, relevance and timeliness of knowledge flows and facilitates cooperation and collaboration among employees (Wang *et al.*, 2011). Employees from different departments can develop common goals, objectives and codes of communication when interacting with suppliers and customers, improving acquisition (Hult *et al.*, 2004). Trust also helps employees collaborate on exchanging and combining acquired knowledge (Nahapiet and Ghoshal, 1998), improving assimilation and application (Jansen *et al.*, 2005; Volberda *et al.*, 2010). Therefore, trust plays a key role in facilitating the development of AC (Marabelli and Newell, 2014). However, close interpersonal relationships alone cannot yield new products. It is the new technological and market knowledge that leads to product innovation (Hult *et al.*, 2006; Zacharia *et al.*, 2011). AC enables a manufacturer to obtain external knowledge, combine and integrate it with existing knowledge and incorporate new knowledge into product designs (Zhang *et al.*, 2015). In particular, acquisition facilitates employees to identify and obtain knowledge regarding markets and product components from customers and suppliers (Lane *et al.*, 2006; Volberda *et al.*, 2010). Assimilation assists employees in analysing and processing acquired knowledge together, which lead to a shared understanding on the impact of the changes in customer preferences on product designs (Hult *et al.*, 2004). Application enables employees to creatively redesign components and product architecture and reconfigure production processes accordingly, helping a manufacturer commercialise knowledge (Zahra and George, 2002). The three components of AC jointly provide a mechanism for employees to leverage knowledge to design new products. Therefore, the following hypothesis is proposed:

H1. AC mediates trust's effect on product innovation.

Information systems provide superior capabilities to communicate with customers and suppliers, support information processing and develop organisational memory (Roberts *et al.*, 2012; Tu *et al.*, 2006), enabling manufacturers to apply past experiences and learned skills to develop new products (Liu *et al.*, 2013). They facilitate a manufacturer to collaborate with external partners across geographic boundaries on a virtual platform, which helps employees reach more suppliers and customers, incorporate their suggestions and respond to market changes swiftly (Malhotra *et al.*, 2005). Information systems also provide formal and standard infrastructure to store, search and retrieve knowledge, enabling a manufacturer to set up routines and reuse technologies and components across different product lines or generations which reduce the costs and lead times for product innovation (Alavi and Leidner, 2001; Liu *et al.*, 2013).

Information systems provide a platform for employees to analyse and transform knowledge collectively, share knowledge among each other and apply prior knowledge in decision making, enhancing AC (Francalanci and Morabito, 2008; Setia and Patel, 2013). However, information technologies alone cannot yield new products. It is the new knowledge about customer preferences and product ideas that leads to product innovation (Hargadon and Sutton, 1997; Zacharia *et al.*, 2011). AC facilitates a manufacturer to learn changes in customer requirements and the specifics of the inputs and outputs of existing products (Lane *et al.*, 2006; Todorova and Durisin, 2007), which are critical for new product development. In particular, acquisition helps a manufacturer obtain feedback on quality and design features of current products (Hult *et al.*, 2004). A manufacturer can also gain knowledge about competitors' products, product improvement suggestions and technology and market development trends from customers and suppliers through acquisition (Lawson and Potter, 2012). Assimilation enables employees to combine and integrate such knowledge with existing knowledge (Nonaka, 1994), and hence employees can continually renew their knowledge stock and develop new applications of existing knowledge (Lane *et al.*, 2006). Application helps employees implement new knowledge and suggestions obtained from both external and internal stakeholders to design new products (Zhang *et al.*, 2015). Hence, the AC components jointly enable a manufacturer to take advantage of existing knowledge and develop new knowledge, enhancing product innovation. Therefore, the following hypothesis is proposed.

H2. AC mediates information systems' effect on product innovation.

Trust improves AC by promoting social interactions among employees (Zahra and George, 2002). Information systems can increase the effectiveness of the interactions. For example, network-based collaboration software and applications enable employees at different locations to have real-time formal or informal interactions to discuss and exchange knowledge, reducing the barriers that constrain the effectiveness of trust (Alavi and Leidner, 2001; Setia and Patel, 2013). Integrated knowledge management systems allow a manufacturer to keep and externalise the knowledge created through social interactions, improving the value of trust on AC (Nonaka, 1994; Roberts *et al.*, 2012). Information systems improve AC by providing tools that facilitate the creation and distribution of knowledge (Liu *et al.*, 2013). Trust among employees ensures that they are willing to use the tools to manage knowledge collectively (Mayer *et al.*, 1995). Trust also motivates employees in different departments to work in teams to learn and internalise the knowledge provided by information systems (Nonaka, 1994; Hotho *et al.*, 2012), increasing the value of information systems on AC. Hence, trust and information systems enhance each other's positive impact on AC. Therefore, the following hypothesis is proposed:

H3. Trust and information systems are complementary in improving AC.

Trust among employees plays a critical role in stimulating favourable attitudes and actions and increasing openness and tolerance for failures within a manufacturer (Yeung *et al.*, 2009). Employees are thus more willing to work together and share their personal and privileged know-how and experiences without worrying that they will be taken advantage of by others (Mayer *et al.*, 1995; Zahra and George, 2002). Commercialising tacit knowledge requires intensive social interactions and collaboration among employees (Hotho *et al.*, 2012). Trust provides a social system that motivates employees to engage in knowledge exploitation and take potential risks associated with exploring novel and creative ideas even when outcomes are unpredictable (Nahapiet and Ghoshal, 1998; Katila and Ahuja, 2002). It can also tackle the barriers, such as the differences in goals, values and backgrounds among employees, when absorbing knowledge for product innovation (Adler and Kwon, 2002; Yeung *et al.*, 2009). Trust among marketing, production and R&D employees thus provides a social system that improves the effectiveness and timeliness of knowledge absorption (Adler and Kwon, 2002; Wang *et al.*, 2011). AC enhances product innovation by providing knowledge inputs and trust can improve the value of the knowledge, thus enhancing AC's positive effect on product innovation. Therefore, the following hypothesis is proposed:

H4. Trust enhances AC's effect on product innovation.

Implementing explicit knowledge requires formal and systematic processes and tools (Nonaka, 1994). Information systems can automatically acquire information using standard formats and routines, process a large amount of information quickly and assist employees in making product development decisions, which help a manufacturer effectively and efficiently explore and exploit knowledge (Katila and Ahuja, 2002; Roberts *et al.*, 2012). Information systems also provide a technical system that facilitates a manufacturer to develop a repository or an integrated database to keep best practices and knowledge and skills learned from past activities and events (Iyengar *et al.*, 2015). They enable employees to apply existing knowledge to absorb new knowledge and reuse past experiences creatively to develop new products, enhancing the value of existing knowledge (Alavi and Leidner, 2001; Hult *et al.*, 2004). Employees can also access, retrieve and use relevant information easily when designing new products (Tu *et al.*, 2006). Hence, employees can cooperate on knowledge commercilisation and incorporate newly absorbed knowledge when making new product development decisions, improving the speed, quantity and quality of product innovation (Hargadon and Sutton, 1997; Kim *et al.*, 2012). Information systems thus increase the value of the knowledge created by AC (Roberts *et al.*, 2012), enhancing AC's positive effect on product innovation. Therefore, the following hypothesis is proposed:

H5. Information systems enhance AC's effect on product innovation.

3. Research method

3.1 Questionnaire design

Based on the relevant literature, a survey instrument was designed to measure a manufacturer's AC, product innovation, trust among employees and information systems. A multiple-item, seven-point Likert-type scale (1 = strongly disagree; 7 = strongly agree) was used for all constructs. In addition, the questionnaire included questions related to the demographic profile of the manufacturers (e.g. industry, ownership and size), R&D collaboration with university and competitor and number of long-term suppliers and customers. The scales are listed in Table AI.

AC was measured by acquisition, assimilation and application (Cohen and Levinthal, 1990; Lane *et al.*, 2006; Todorova and Durisin, 2007). In particular, acquisition was measured by four items related to the routines and procedures for interacting with customers and suppliers (Zhang *et al.*, 2015). They were developed based on the studies by Jansen *et al.* (2005) and Hult *et al.* (2004), and were adapted to the supply chain context. Assimilation was measured by four items related to the mechanisms and processes used to analyse, convert and distribute knowledge within a manufacturer (Todorova and Durisin, 2007). Two items gauging group learning and knowledge distribution were adapted from Jansen *et al.* (2005) and two new items on problem solving and training were added based on Zahra and George (2002). Application was measured by four items related to the routines and capabilities of incorporating knowledge into operations (Cohen and Levinthal, 1990). One item about knowledge exploitation was adapted from Jansen *et al.* (2005). Three new items related to making improvement suggestions, discovering new opportunities and reviewing long-term forecasting based on new knowledge were developed based on Zahra and George (2002).

Product innovation was measured by four items regarding both radical and incremental innovation (Ritala and Hurmelinna-Laukkanen, 2013). They were developed based on the studies by Damanpour (2010) and Kim *et al.* (2012). Trust was measured by three items about the relationships among the employees in marketing, R&D and production departments (Mayer *et al.*, 1995; Yeung *et al.*, 2009). Four items capturing outside-in information systems, internal knowledge management systems and network applications were used to measure information systems. They were developed based on the studies by Roberts *et al.* (2012) and Alavi and Leidner (2001).

We included six control variables that may influence product innovation and AC in the analyses. Large manufacturers are more likely to innovate and have higher levels of AC because they have more financial and technical capabilities and specialised personnel dedicated to innovation and knowledge management, and due to the economies of scale and scope to spread the risk of failure and the costs of innovation and knowledge creation (Damanpour, 2010). Firm size was measured by the number of employees (Un *et al.*, 2010; Wang *et al.*, 2011). Product innovation and AC can also be influenced by industry-wide factors, such as technological infrastructure, demand patterns, competition intensity and clock speed (Mazzola, Perrone, and Kamuriwo, 2015). Three dummy variables were used to measure the four industries. In addition, researchers argue that R&D collaboration with university/competitor may influence product innovation and AC because they can provide a manufacturer additional resources and knowledge (Un *et al.*, 2010; Mazzola, Perrone, and Kamuriwo, 2015). Hence, we controlled R&D collaboration with university/competitor which were measured using four items about the degree of and resource investments in R&D collaborations. Moreover, we controlled the number of long-term suppliers/customers (i.e. the suppliers/customers that have collaborated with a manufacturer for more than three years) because the more supply chain relations the more a manufacturer develops routines that can increase AC (Mazzola, Bruccoleri, and Perrone, 2015). The natural logarithm of the number of long-term suppliers/customers was used in analyses.

The questionnaire was first developed in English and subsequently translated into Chinese by a professor. The Chinese version was then translated back into English by another professor. This translated English version was then checked against the original English version for any discrepancies, and adjustments were made to reflect the original meaning of the questions in English. The questionnaire was pilot tested using a sample of 13 manufacturers before its full-scale launch. The research team discussed the questions face-to-face with managers after they filled out the questionnaire and clarified the meaning of the questions with them. When any confusion arose, the wording of the questions was modified.

3.2 Sampling and data collection

To test the hypotheses, manufacturing firms were randomly selected from four industries (i.e. textile and apparel, electrical appliances, electronics and communication equipment and automobile) in four major areas (i.e. Pearl River Delta, Yangtze River Delta, Bohai Sea Economic Area and Central China) that represent the national economy of China. The database provided by CSMAR Solution (http://csmar.gtadata.com/) was used as the sampling frame.

China provides an interesting testbed for the hypotheses. Due to the increasing labour and land costs, the cheap China is ending and Chinese manufacturers are competing through product innovation (Zhang *et al.*, 2016). However, China has an underdeveloped legal system to provide sufficient protection for manufacturers' intellectual property rights and the enforcement of law is also problematic (Wang *et al.*, 2011). Hence, Chinese manufacturers tend to develop new products by localising and adapting existing technologies and products to Chinese markets (Zhang *et al.*, 2016). Such creative adaptation is driven by the knowledge about supply chains and local markets and a manufacturer's AC. In addition, Chinese culture is characterised by collectivism and long-term orientation (Yeung *et al.*, 2009). Trust among employees thus plays a very important role in facilitating collaborative knowledge creation and new product development. Moreover, along with the economic development, information and communication technology infrastructure has been evolving rapidly in China, and network-based information systems have also been widely implemented by Chinese manufacturers.

After pilot-testing the questionnaire, it was decided to use one key informant who was knowledgeable on knowledge management routines and processes and was familiar with new product development, production processes and supply chain management. Potential key informants included supply chain managers, production managers, R&D managers, presidents, senior executives and directors. Questionnaires were sent to 1,460 randomly selected manufacturers, but 133 of them were returned unopened. The research team finally collected 276 usable questionnaires. Hence, the response rate is 20.8 per cent. The sample demographics are shown in Table I.

Since the survey data were obtained from single informants, common method variance (CMV) might be a concern. Several steps have been taken to control CMV. In particular, we provided a clear guideline and a glossary of terms at the end of the survey and arranged the order of the scale items randomly. We also prequalified potential respondents to ensure the informants were mid- and senior-level managers with high levels of relevant knowledge and assured the informants their responses would be kept anonymous. In addition, this study used multiple items for each construct, which alleviates concerns for CMV, since potential biases tend to be more problematic at the item level than the construct level. Following Podsakoff *et al.* (2003), Harman's single factor test was performed on the acquisition, assimilation, application, product innovation, trust, information system, R&D collaboration with university and R&D collaboration with competitor variables using exploratory factor analysis. The results show eight distinct factors with eigenvalues above or near 1.0, explaining 68.72 per cent of the total variance. Moreover, the first factor does not explain most the total variance, which is acceptable for this study where the constructs are correlated, both conceptually and empirically. To further assess CMV, confirmatory factor analysis (CFA) was also applied to perform the Harman's single factor test. The model fit indices are $\chi^2(434) = 3321.583$, $\chi^2/\text{df} = 7.653$, comparative fit index (CFI) = 0.460, Tucker Lewis index (TLI) = 0.421, root mean square error of approximation (RMSEA) = 0.156 and standardized root mean square residual (SRMR) = 0.134, which are unacceptable (Hu and Bentler, 1999). The results suggest that no single or general factor emerges. As a third test of

Table I. Company profiles

Industry	Number of companies (percentage)	Ownership	Number of companies (percentage)	Number of employees	Number of companies (percentage)	Sales (million RMB)[a]	Number of companies (percentage)
Electrical appliance	30 (10.87)	Collectively owned	5 (1.87)	$<=300$	95 (34.42)	<5	14 (5.19)
Textile and apparel	63 (22.83)	Joint venture	36 (13.43)	301-1,000	63 (22.82)	5-10	22 (8.15)
Automobile	69 (25.00)	Foreign owned	49 (18.28)	1,001-3,000	38 (13.77)	11-30	31 (11.48)
Electronics and communication equipment	114 (41.30)	State owned	52 (19.40)	$>3,000$	80 (28.99)	31-50	19 (7.04)
Total	276	Privately owned	126 (47.01)	Total	276	51-100	23 (8.52)
		Total	268			101-300	34 (12.59)
						301-1,000	29 (10.74)
						$>1,000$	98 (36.30)
						Total	270

Note: [a]1 US$ = 6.34 RMB

CMV, controlling for the effects of an unmeasured latent methods factor technique was used (Podsakoff *et al.*, 2003). In particular, one measurement model including only the traits and one including a latent CMV factor in addition to the traits (i.e. items were allowed to load on their theoretical constructs as well as on the latent CMV factor) were tested (Podsakoff *et al.*, 2003). The model fit indices of the second model improve marginally. The path coefficients of the trait factors and their significance levels are similar between the two models, suggesting that they are robust, despite the inclusion of the latent CMV factor. Therefore, CMV is not a significant threat in this study.

3.3 Reliability and validity

Reliability was assessed in terms of composite reliability and Cronbach's α (Fornell and Larcker, 1981). The values of composite reliability and Cronbach's α range from 0.830 to 0.951 and from 0.734 to 0.923, respectively (Table AI), which are all above the recommended threshold value of 0.70, suggesting adequate reliability.

Convergent validity was assessed by the average variance extracted (AVE). Table AI shows that all of the AVE values are above the recommended value of 0.50 (ranging from 0.551 to 0.866), which demonstrate adequate convergent validity (Fornell and Larcker, 1981). A measurement model was constructed using CFA to further assess convergent validity. In the model, the items for AC were linked first to the constructs of acquisition, assimilation and application, which then loaded onto the AC construct, and the items for trust, information system, product innovation, R&D collaboration with university and R&D collaboration with competitor were directly linked to corresponding constructs. The covariance among the constructs was freely estimated. The resulting model fit indices are $\chi^2(416) = 862.963$, $\chi^2/\text{df} = 2.074$, CFI = 0.916, TLI = 0.907, RMSEA = 0.063 and SRMR = 0.057, which are better than the threshold values recommended by Hu and Bentler (1999). The factor loadings range from 0.584 to 0.958, and the *t*-statistics of the factor loadings are all significant at the $p < 0.01$ level (Table AI). Therefore, convergent validity is achieved (Fornell and Larcker, 1981).

Discriminant validity was assessed by comparing the square roots of the AVE of each construct with the correlations between the focal construct and each other construct. A square root higher than the correlations with other constructs suggests discriminant validity (Fornell and Larcker, 1981). Table II shows the mean and standard deviation of the constructs and their correlations. Comparisons of all the correlations and square roots of the AVEs on the diagonal indicate adequate discriminant validity for all constructs. Discriminant validity was further assessed by using constrained measurement models for each possible pair of constructs in which the correlation between this pair of constructs was fixed to 1. The constrained measurement models were subsequently compared to the original unconstrained measurement model in which the correlations among constructs were freely estimated. In this study, all the χ^2 differences between the constrained and unconstrained models are significant at the 0.01 level. As such, discriminant validity is achieved (Fornell and Larcker, 1981).

4. Analysis and results

Hierarchical regression and bootstrapping methods are used to test the hypotheses. To mitigate the potential threat of multi-collinearity, the variables are mean-centred prior to the formation of interaction terms, as recommended by Aiken and West (1991). Furthermore, we calculate variance inflation factors (VIFs) in each of the regression equations. The maximum VIF within the models is 2.37, which is well below the rule-of-thumb cut-off of 10 (Aiken and West, 1991).

Baron and Kenny (1986)'s method is used to test the mediating role of AC and the results are presented in Table III. AC is used as the dependent variable in model 1. The result shows

Table II.
Descriptive statistics

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
Acquisition (X1)	*0.802*									
Assimilation (X2)	0.591**	*0.849*								
Application (X3)	0.656**	0.703**	*0.777*							
Trust (X4)	0.432**	0.377**	0.553**	*0.931*						
Information system (X5)	0.648**	0.575**	0.552**	0.343**	*0.742*					
Product innovation (X6)	0.476**	0.351**	0.388**	0.355**	0.411**	*0.863*				
R&D collaboration with university (X7)	0.326**	0.294**	0.295**	0.170**	0.353**	0.232**	*0.899*			
R&D collaboration with competitor (X8)	0.278**	0.240**	0.219**	0.192**	0.195**	0.129	0.551**	*0.851*		
Number of long-term suppliers (X9)	0.158**	0.089	0.107	−0.017	0.268**	0.088	0.189**	0.024	N/A	
Number of long-term customers (X10)	0.173**	0.089	0.122*	0.054	0.199**	0.093	0.229**	0.092	0.508**	N/A
Mean	5.024	4.838	4.949	5.612	5.495	5.119	4.049	3.920	3.569	3.163
SD	1.119	1.179	1.047	1.168	1.033	1.091	1.655	1.452	1.730	1.510

Notes: Square root of average variance extracted (AVE) is shown on the diagonal of the matrix in italic and inter-construct correlation is shown off the diagonal. The natural logarithm of the number of long-term suppliers/customers is used in the analysis. **$p < 0.01$; *$p < 0.05$

Table III.
Results of regression analysis: mediation and interaction effects

	AC		Product innovation	
	Model 1	Model 2	Model 3	Model 4
Control variables				
Industry				
Electrical appliance	−0.098	−0.078	0.049	0.074
Textile and apparel	0.039	0.045	0.031	0.020
Automobile	−0.025	−0.003	−0.063	−0.056
Firm size				
< = 300	−0.034	−0.038	−0.013	−0.004
301-1,000	−0.020	−0.018	0.001	0.006
1,001-3,000	−0.084	−0.064	−0.003	0.019
R&D collaboration with university	0.067	0.061	0.110	0.093
R&D collaboration with competitor	0.089	0.068	−0.038	−0.061
Number of long-term suppliers	−0.036	−0.040	0.020	0.029
Number of long-term customers	0.043	0.036	−0.009	−0.021
Independent variables				
Trust	0.287***	0.149	0.230***	0.120
Information system	0.544***	0.398***	0.300***	0.134
Trust × Information system		0.211**		
AC				0.262**
R^2	0.579	0.596	0.236	0.265
F-value	30.137***	29.704***	6.776***	7.268***
R^2 change		0.017		0.029
F change		10.897**		10.298**

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

that trust ($b = 0.287$, $p < 0.001$) and information systems ($b = 0.544$, $p < 0.001$) have significant effects on AC, indicating that the independent variables (i.e. trust and information systems) significantly influence the mediator (i.e. AC). Then, the interaction between trust and information systems is entered in model 2 and the result shows that it ($b = 0.211$, $p < 0.01$) positively affects AC. Therefore, trust and information systems are complementary in improving AC, supporting *H3*. Product innovation is used as the dependent variable in models 3 and 4. Model 3 reveals that trust ($b = 0.230$, $p < 0.001$) and information systems ($b = 0.300$, $p < 0.001$) have significant effects on product innovation, indicating that the independent variables significantly influence the dependent variable (i.e. product innovation). Then, we add AC in model 4, the result shows that AC ($b = 0.262$, $p < 0.01$) has a significant effect on product innovation. However, the effects of trust and information systems become non-significant, indicating that including the mediator in the model reduces the effects of the independent variables to non-significance. We also examine the indirect effects of trust and information systems on product innovation through AC using the bias-corrected bootstrapping method with a 95 per cent confidence level and 5,000 samples (Preacher and Hayes, 2008). The results show that the indirect effect of trust on product innovation through AC is 0.183 and the bias-corrected 95 per cent confidence interval of the indirect effect is (0.119, 0.255). The indirect effect of information systems on product innovation is 0.243 and the bias-corrected 95 per cent confidence interval of the indirect effect is (0.124, 0.358). Hence, the findings suggest that AC fully mediates the effects of trust and information systems on product innovation, supporting *H1* and *H2*.

The moderating effects of trust and information systems are tested by examining the interactions between the independent variable (i.e. AC) and moderators (i.e. trust and information systems) (Baron and Kenny, 1986) and the results are presented in Table IV. Product innovation is used as the dependent variable in all three models. Model 1 includes the control, independent and moderator variables. The result demonstrates that AC ($b = 0.262$, $p < 0.01$) significantly influences product innovation. Then, the interactions

	Product innovation		
	Model 1	Model 2	Model 3
Control variables			
Industry			
Electrical appliance	0.074	0.064	0.054
Textile and apparel	0.020	0.020	0.061
Automobile	−0.056	−0.066	−0.059
Firm size			
< = 300	−0.004	−0.013	−0.006
301-1,000	0.006	0.013	0.012
1,001-3,000	0.019	0.010	0.029
R&D collaboration with university	0.093	0.086	0.098
R&D collaboration with competitor	−0.061	−0.057	−0.064
Number of long-term suppliers	0.029	0.031	0.008
Number of long-term customers	−0.021	−0.026	−0.027
Main effects			
Trust	0.120	0.156*	0.124
Information system	0.134	0.121	0.202**
AC	0.262**	0.270**	0.264**
Moderating effects			
AC × Trust		0.138*	
AC × Information system			0.224***
R^2	0.265	0.281	0.305
F-value	7.268***	7.286***	8.178***
R^2 change		0.016	0.040
F change		5.787*	14.967***

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table IV. Results of regression analysis: moderation effects between AC and trust and between AC and information systems are entered in models 2 and 3, respectively. We find that the interaction between AC and trust ($b = 0.138, p < 0.05$) and the interaction between AC and information systems ($b = 0.224, p < 0.001$) significantly affect product innovation, indicating that trust and information systems positively moderate the effect of AC on product innovation (Baron and Kenny, 1986).

Because the effects of trust and information systems on product innovation are mediated by AC, we test the moderated mediation effects using the bootstrapping method (Preacher *et al.*, 2007). The moderators (i.e. trust and information systems) are set at three different values (i.e. mean and ±1 standard deviation), and then the indirect effects of trust and information systems on product innovation through AC are estimated using the bias-corrected bootstrapping method with a 95 per cent confidence level and 5,000 samples (Preacher *et al.*, 2007). The bias-corrected 95 per cent confidence intervals when the trust values are set at mean (5.612), one standard deviation above the mean (6.780) and one standard deviation below the mean (4.444) are (0.124, 0.258), (0.154, 0.351) and (0.054, 0.235), respectively. The bias-corrected 95 per cent confidence intervals when the information systems values are set at mean (5.495), one standard deviation above the mean (6.528) and one standard deviation below the mean (4.462) are (0.138, 0.364), (0.218, 0.501) and (0.020, 0.274), respectively. All these confidence intervals are positive and different from zero, suggesting that trust and information systems moderate the impact of AC on product innovation after accounting for the relationships between trust and information systems and AC (Preacher *et al.*, 2007). Therefore, *H4* and *H5* are supported.

5. Discussion and conclusions

5.1 Theoretical contributions

This study contributes to operations management literature in three ways. First, the findings provide empirical evidence that trust and information systems enhance AC's effect on product innovation. Researchers find that AC facilitates knowledge transfer and innovation (Lawson and Potter, 2012; Nagati and Rebolledo, 2012; Tavani *et al.*, 2014). Empirical evidence also exists that AC's effects are moderated by environmental conditions (Setia and Patel, 2013; Saenz *et al.*, 2014) and supply chain partner's capabilities (Whitehead *et al.*, 2016). This study further reveals that a manufacturer's sociotechnical systems moderate the relationship between AC and product innovation, enhancing current understandings on the contingencies that influence AC's effects and how to fully reap AC's benefits on new product development (Volberda *et al.*, 2010; Lawson and Potter, 2012). By building a moderated mediation model, we link AC and product innovation with trust and information systems, providing insights into how to design organisational systems to enhance the effectiveness of knowledge management processes (Hult *et al.*, 2006). In addition, this study adopts a capability view of AC and explicitly captures the acquisition, assimilation and application processes (Lane *et al.*, 2006; Roberts *et al.*, 2012). The findings enrich existing knowledge on how to design knowledge management processes to absorb and leverage knowledge for new product development (Tavani *et al.*, 2014; Whitehead *et al.*, 2016).

Second, this study provides empirical evidence that trust and information systems improve AC both individually and interactively, extending current understandings on the antecedents of AC (Marabelli and Newell, 2014). The majority of existing empirical studies focus on the effects of either socialisation (Zahra and George, 2002; Jansen *et al.*, 2005) or information technology (Roberts *et al.*, 2012; Setia and Patel, 2013) capabilities on AC development. We take an integrative view on a manufacturer's sociotechnical systems and simultaneously investigate the effects of trust among employees and information systems on AC. The findings reveal that trust and information systems are complementary in improving AC, highlighting the importance of co-designing social and technical systems in developing AC (Lane *et al.*, 2006; Volberda *et al.*, 2010). The results also provide a holistic picture on the complex relationships between an organisation's sociotechnical systems and knowledge management processes.

Third, this study finds that AC mediates the effects of trust and information systems on product innovation, providing insights into how to fully capitalise the relationships among employees and information technologies for new product development (Calantone *et al.*, 2002; Swink and Song, 2007; Roberts *et al.*, 2012). The results show that both trust and information systems improve new product development indirectly through AC which enhances current understandings of how trust, information systems and AC interact to affect product innovation (Hotho *et al.*, 2012; Saenz *et al.*, 2014; Marabelli and Newell, 2014). This study also reveals that a moderated mediation relationship exists among a manufacturer's sociotechnical systems, AC and product innovation, suggesting that a manufacturer should jointly design its organisational systems and knowledge management processes to support new product development (Lane *et al.*, 2006; Mazzola, Bruccoleri, and Perrone, 2015).

5.2 Managerial implications

This study provides guidelines that help operations managers understand knowledge management better and how to design organisational systems to develop AC and reap the benefits of AC on new product development. The findings reveal that AC can help manufacturers develop new products and highlight the need for managers to develop knowledge management processes that include both external-facing and internal components. Hence, we suggest managers organise focus groups and brainstorming sessions with customers and suppliers. Standard operating procedures should be developed to guide employee's interactions with customers and suppliers, such as pre-sale and after-sale visits and supplier evaluation and auditing. In addition, managers must be aware that building routines and procedures for acquiring knowledge alone is not enough. Manufacturers who want to take full advantage of the knowledge residing in supply chains on new product development should invest in internal processes that emphasise knowledge assimilation and application at the same time. For example, learning groups and problem solving teams that involve representatives from multiple functions should be formed to share information, discuss improvement suggestions and coordinate decisions. Managers should design training programmes to improve employees' information processing skills and distribute existing knowledge and past successful experiences to them. Executive meetings should be held regularly to discuss new business opportunities and review long-term forecasting about market and technology development trends to provide strategic guidelines for product innovation.

This study reveals that trust among employees and information systems improve product innovation indirectly through AC and enhance AC's effect on product innovation. They also have both individual and interactive effects on AC. The findings indicate that AC' effects are contingent upon the sociotechnical systems of a manufacturer. Hence, a manufacturer may not be able to gain full advantage of AC on new product development without investments in organisational systems. Managers should pay attention to the design of sociotechnical systems to support knowledge management and new product development, given their important effects in maximising the potential value of AC and the synergies between AC and trust and information systems. Therefore, we suggest manufacturers invest in formal and informal arrangements to build trust among employees and develop network-based information and knowledge management systems at the same time. In particular, managers should empower employees to interact with colleagues across functional boundaries and build horizontal channels for cross-functional collaboration. Social events, such as conferences, workshops and parties, should be organised to help employees interact with each other. Providing feedback about successful product development projects can help employees develop positive expectations about colleagues' goodwill and competence. Manufacturers should also invest in information technologies such as enterprise resource planning systems, integrated databases and collaboration software and applications, and motivate employees to use these tools to process and implement knowledge collaboratively. Managers should develop rules and regulations about how knowledge, such as results of group discussion, employee suggestions, successful product development experiences and lessons learned from product failures, is codified, stored and retrieved using information systems. Regular training programmes and manuals regarding how to use information systems should be provided to employees.

5.3 Limitations and future research directions

While this study makes significant theoretical and practical contributions, it has limitations that open up avenues for future research. First, we conduct this study in China. The relationships among trust, information systems, AC and product innovation might be influenced by the Chinese business, cultural and institutional environments. Future research could examine the research model in other countries to generalise the findings. Second, this study tests the research model using cross-sectional data. Researchers argue that innovation may influence AC (Cohen and Levinthal, 1990) and an orgranisational environment promoting innovation may improve trust among employees (Adler and Kwon, 2002). Future research could extend the study by using a longitudinal design to investigate the evolution and dynamics among trust, AC and innovation. Third, this study may have the problem of endogeneity because some uncontrolled confounders may cause both independent and dependent variables of the model, which is a limitation. Fourth, researchers argue that relational embeddedness in an innovation network positively influences AC (Mazzola, Bruccoleri, and Perrone, 2015). Exploring the impact of supply chain relationship on the linkage between AC and new product development is an interesting topic. Fifth, this study focusses on both incremental and radical product innovation. Researchers argue that incremental and radical innovation is associated with exploitative and exploratory learning, respectively (Hargadon and Sutton, 1997; Katila and Ahuja, 2002), and a firm's AC may employ different levels of exploitation and exploration (Lane *et al.*, 2006). Future studies could investigate how different types of AC influence incremental and radical innovation. Sixth, this study does not consider internal R&D investments, which is a limitation (Cohen and Levinthal, 1990). Future studies could examine the impacts of internal R&D investments on acquisition, assimilation and application processes.

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Appendix

	Loading[a]
Absorptive capacity	
Acquisition CR = 0.879, α = 0.816, AVE = 0.644	0.892
We periodically organise special meetings with customers (e.g. focus groups and brainstorming sessions) to find out what products/services are needed in the future	0.725
We have formal routines and standard operating procedures to guide employees' interactions with customers	0.711
We periodically organise special meetings with suppliers (e.g. focus groups and brainstorming sessions) to find out what products/services are needed in the future	0.741
We have formal routines and standard operating procedures to guide employees' interactions with suppliers	0.725
Assimilation CR = 0.911, α = 0.870, AVE = 0.720	0.831
We regularly organise learning groups to discuss the consequences of new knowledge	0.780
We have special mechanisms to solve conflict when employees have different understandings and interpretations of new knowledge	0.764
We have special procedures for employees to share knowledge and practical experiences	0.839
We have special training programmes that help employees grasp new knowledge	0.787
Application CR = 0.858, α = 0.780, AVE = 0.603	0.944
Our employees frequently make improvement suggestions (e.g. products and processes) based on new knowledge	0.668
We have systematic procedures for discovering new business opportunities based on new knowledge	0.736
We periodically review our long-term forecasting (e.g. market trends and technology development) based on new knowledge	0.646
We constantly consider how to better exploit knowledge	0.698
Trust CR = 0.951, α = 0.923, AVE = 0.866	
The employees in production and R&D departments trust each other	0.872
The employees in production and marketing departments trust each other	0.887
The employees in marketing and R&D departments trust each other	0.924
Information system CR = 0.830, α = 0.734, AVE = 0.551	
Our company uses network-based collaboration software and applications (e.g. office automation)	0.610
Our company uses integrated knowledge management systems (e.g. discussion forum and database)	0.734
We and our customers are connected by network-based information systems	0.584
We and our suppliers are connected by network-based information systems	0.609
Product innovation CR = 0.921, α = 0.886, AVE = 0.745	
We can introduce new products quickly	0.831
We are highly capable of incremental product innovation	0.866
We are highly capable of radical product innovation	0.813
We can design new products that differ substantially from our existing products based on new technologies	0.746
R&D collaboration with university CR = 0.944, α = 0.921, AVE = 0.808	
We frequently collaborate with universities on R&D	0.786
We have invested a lot of human resources to collaborate with universities on R&D	0.958
We have invested a lot of financial resources to collaborate with universities on R&D	0.929
We collaborate with universities on many R&D projects	0.772
R&D collaboration with competitor CR = 0.913, α = 0.871, AVE = 0.724	
We frequently collaborate with competitors on R&D	0.632
We have invested a lot of human resources to collaborate with competitors on R&D	0.890
We have invested a lot of financial resources to collaborate with competitors on R&D	0.878
We collaborate with competitors on many R&D projects	0.779

Notes: CR, composite reliability; α, Cronbach's α; AVE, average variance extracted. [a]All item loadings are significant at the $p < 0.01$ level (t values range from 9.115 to 22.067)

Table AI.
Measurement items

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