Industrial Marketing Management 49 (2015) 128–138

Contents lists available at ScienceDirect

Industrial Marketing Management

Influences of cross-functional collaboration and knowledge creation on technology commercialization: Evidence from high-tech industries

Yichen Lin [a,*], Yichuan Wang [b,1], LeeAnn Kung [c,2]

[a] Department of Business and Management, National University of Tainan, No. 33, Shulin St., Sec. 2, Tainan, Taiwan, ROC
[b] Raymond J. Harbert College of Business, Auburn University, 405 W. Magnolia Ave., Auburn, AL 36849, United States
[c] Department of Marketing/Business Information Systems, Rowan University, Glassboro, NJ 08028, United States

A R T I C L E I N F O

Article history:
Received 18 December 2012
Received in revised form 8 December 2014
Accepted 30 December 2014
Available online 1 May 2015

Keywords:
Cross-functional collaboration
Technology commercialization
Knowledge creation
Knowledge-based view
High-tech industries

A B S T R A C T

Technology commercialization (TC) contributes to maintaining the competitive advantage of high-tech firms, but although researchers have established that product innovation and new product development are enhanced by cross-functional collaboration and organizational knowledge activities, this may not be the case for TC. Drawing on the knowledge-based view and the influence of cross-functional collaboration, the main goal of this study is to unravel the relationships among cross-functional collaboration, knowledge creation and TC performance in the high-tech industry context. Empirical findings from our survey of 203 marketing and R&D managers and employees in Taiwanese high-tech companies indicate that cross-function collaboration reveals fresh opportunities for creating knowledge and commercializing technologies. Our results also suggest that knowledge creation plays an important role in TC performance by partially mediating the relationship between cross-functional collaboration and TC performance. The contributions of this study provide new insights into industrial marketing literature by proposing a cross-functional collaboration-enabled TC model that takes into account the effect of knowledge creation.

1. Introduction

High-tech firms have increasingly focused on technology commercialization (TC) as a means of maintaining their competitive advantage over the past two decades (Galbraith, DeNoble, & Ehrlich, 2012; Jolly, 1997; Lin, Lee, & Hung, 2006; Zahra & Nielsen, 2002). From a process perspective, technology commercialization is defined as "the process that begins with imagining a techno-market insight, incubating the technology to define its commercializability, demonstrating it contextually in products and process, promoting the latter's adoption, and ultimately sustaining commercialization (Jolly, 1997, p. 3)." From an organizational capability perspective, TC can be viewed as the ability to absorb and re-adapt a new technology for use in production and marketing (Kim, Lee, Park, & Oh, 2011). According to a report from Oracle, in most high-tech companies 10–20% of their annual revenue is invested in new product development activities, and a significant percentage of the company's market value is based on how many new technologies are on the path to commercialization (Goyal, 2006). Successful TC enables high-tech firms to meet their customers' needs, get ahead of their competitors and increase their profits, but to maximize the effectiveness of TC these firms need to begin by developing a good theoretical understanding of the factors that impact the commercialization of new technologies.

Although the literature on investigating the relationship between cross-functional collaboration and NPD or product innovation is abundant (e.g., De Luca & Atuahene-Gima, 2007; Lin, Hsing, & Wang, 2008; Song & Thieme, 2006), previous findings might not be directly applicable to the particular context of commercializing new technologies due to the natural differences in objective, time scale, stakeholders, and nature of demand between NPD and TC (Jolly, 1997). For example, Jolly (1997) examines perspectives such as object, time scale, nature of demand, and marketing challenges to explain the differences between NPD and TC, but notes that the TC process involves a tighter focusing of technical ideas or inventions on specific objectives than either NPD (Jolly, 1997; Kodama, 1992). As the TC process begins with basic scientific or technical research, often involving the awarding of patents, it can take a long time to realize the value of the products (Jolly, 1997). Product innovation and NPD, on the other hand, focus on the development of entirely new products that exploit existing products, or modify existing products in a new application (Atuahene-Gima, 2005). TC not only emphasizes product innovation, but also converts basic scientific or technical research into feasible and salable products (Jolly, 1997). This insight provides an excellent opportunity for industrial marketing researchers to investigate the impacts of

* Corresponding author. Tel.: +886 6 2606123x7735; fax: +886 6 2606173.
E-mail addresses: yichen@mail.nutn.edu.tw (Y. Lin), yzw0037@auburn.edu (Y. Wang), kung@rowan.edu (L. Kung).
[1] Tel.: +1 318 278 4630.
[2] Tel.: +1 856 256 4029.

http://dx.doi.org/10.1016/j.indmarman.2015.04.002
0019-8501/

cross-functional collaboration on TC since there is a paucity of research in this domain (Aggarwal & Hsu, 2009; Zahra & Nielsen, 2002).

Moreover, recent studies (e.g., Baraldi, Ingemansson, & Launderg, 2014; Boehm & Hogan, 2013; Medli & Törnroos, 2014) have focused on the TC context, and underscored that integrating insights from two or more organizations for commercializing a technology will gain different advantages from an objective, which is likely to result in increasing firms' benefits of commercialization and helping maintain its long-term competitive edge. This applies especially to high-tech industries, where the innovation process and product life cycle times are shorter than those of traditional manufacturing industries. Surprisingly, the relationship between CFC and TC has not been empirically tested. Following this logic, we examine the impact of CFC, specifically R&D and marketing collaboration on TC performance in the context of high-tech industries.

In addition to the impact of CFC, knowledge is one of the most important resources supporting a firm's primary activities (Grant, 1996), particularly those related to TC (Frishammar, Lichtenthaler, & Rundquist, 2012). Organizational knowledge creation is embedded in the commercialization process and thus directly affects TC performance (Frishammar et al., 2012; Mir & Rahaman, 2003). In order to facilitate this process, organizations need to develop a knowledge creation mechanism, which is often achieved through a collaborative working environment (Samaddar & Kadiyala, 2006). This path has not been studied explicitly in the literature, so to address this gap in the research we sought to answer the following research question: does cross-functional collaboration affect the technology commercialization performance of high-tech manufacturers through knowledge creation?

To answer this research question, we empirically examined the direct effect of cross-functional collaboration and knowledge creation on TC and then went on to test the mediating role of knowledge creation. The next section reviews the existing literature and develops the hypotheses guiding this research. Section 3 describes the research methodology, and we present the data analysis and discuss our results in Section 4. Finally, Section 5 assesses the contributions of this study and considers the implications for management scholars and practitioners.

2. Research model and hypothesis development

In order to understand the keys to improve technology commercialization performance, we anchored our theoretical treatment in the knowledge-based view (KBV) and the influence of CFC. KBV not only considers knowledge as a strategically significant resource of a firm, but also emphasizes the importance of knowledge creation for the production of goods and services, as well as for gaining a competitive advantage (Grant, 1996; Kogut & Zander, 1992). TC comprises the entire process of transferring a new idea or technology into salable goods (Jolly, 1997) and thus includes product conception and definition from new technologies, product design and prototyping tests, and product manufacturing and marketing (Zahra & Nielsen, 2002), all of which are associated with knowledge creation in an organization (Jolly, 1997; Mir & Rahaman, 2003). Knowledge creation has been described as a spiral process of socialization, externalization, combination and internalization that creates knowledge (Nonaka & Konno, 1998; Nonaka & Takeuchi, 1995).

However, an effective knowledge creation is not likely to be achieved by a formal hierarchy and structure under central control (Rylander & Peppard, 2004). Instead, effective organizational knowledge creation can result from the synthesis of different individuals' views from the different functional units, for example, which is a collaborative organizational learning process (De Luca & Atuahene-Gima, 2007; Grant, 1996). Previous studies have indicated that the significant effect of cross-functional collaborations on product innovation performance is through knowledge integration activities (De Luca & Atuahene-Gima, 2007). Integrating these insights, we propose that cross-functional collaboration actually follows dual paths to affect TC (Fig. 1). In the first path, cross-functional collaboration directly influences TC performance, while in the second, cross-functional collaboration indirectly impacts TC performance through knowledge creation.

Four types of TC performance outcomes are included in the new conceptual framework proposed here: the number of new products, speedier introduction of new products, future market potential, and effective use of patents and know-how. These measurements for TC are derived from the expected outcomes of the TC process (Jolly, 1997). The number of new products refers to how many of the firm's new products are gaining acceptance in various markets (Jolly, 1997). The speedier introduction of new product refers to the ability to shorten the time required for the TC process, thus allowing the firm to introduce new products more quickly than its competitors (Zahra & Nielsen, 2002). The future market potential refers to the exciting, preferably unique, technology-based ideas that are linked to a future market's needs (Jolly, 1997). The effective use of patents and know-how refers to the extent to which an organization can realize the idea, exploit its commercial potential, and plan ways to take it further (Jolly, 1997). These performance outcomes are considered to be simultaneously involved in the construct of TC performance in this study. Fig. 1 presents the new conceptual model.

2.1. Effect of cross-functional collaboration on technology commercialization

Cross-functional collaboration refers to a team consisting of members who are from about the same hierarchical level but from different work areas who come together to accomplish a specific task (Robbins, 2001); typical examples are research & development (R&D)–marketing collaborations and R&D–manufacturing collaborations. The existing literature has clearly demonstrated that the effects of collaboration mechanism such as science-to-business collaborations (Boehm & Hogan, 2013), inter-organizational interactions regarding action, result, and personal (Baraldi et al., 2014), and diverse networks (Aarikka-Stenroos, Sandberg, & Lehtimäki, 2014) are all known to be important to the success of TC performance. In this study, we focus on studying the cross-functional collaboration and examining their effects on TC performance. More specifically, we examine the impact of CFC regarding organizational behavior factors, largely because most of the

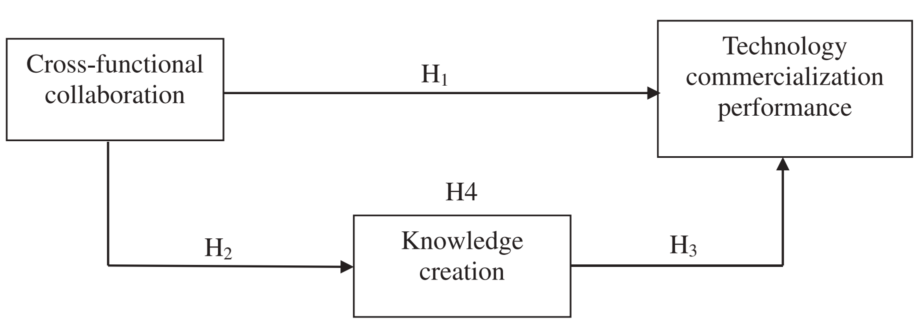

Fig. 1. Research model.

barriers to cross-functional collaboration are linked to organizational member behaviors. For example, previous studies have described the difficulty in creating a coherent, integrated team due to interfunctional conflicts, team leader autonomy conflicts with team members, and a lack of goal congruency, all of which can be serious barriers hampering cross-functional collaboration (Lovelace, Shapiro, & Weingart, 2001; Song, Xie, & Dyer, 2000; Song, Kawakami, & Stringfellow, 2010; Xie, Song, & Stringfellow, 1998, 2003). Such barriers interfere with the generation of good ideas or new knowledge and can delay the commercialization process considerably (Shaw, Shaw, & Enke, 2003).

Moreover, we found that cross-functional collaboration has a multidimensional nature. Thus, cross-functional collaboration is modeled as a latent construct reflected by a set of four prominent facets in this study, namely collaborative relationships, collaborative leadership, communicating and sharing information, and trust formation. These are described in turn below.

Collaborative relationships refer to building the type of relationship that enables team members to integrate their resources (Stalk & Hout, 1990), exchange information (Perks, 2000) and learn about each other's knowledge and capabilities (Holland, Gaston, & Gomes, 2000) as part of a collaborative team. This relationship can enhance intergroup interactions and solve problems by developing a more thorough view of the whole organization and processes, leading to successful TC (Ettlie, 1995). When a collaborative mechanism is effective, the members of a cross-functional team can contribute to the commercialization process by developing new ideas or creating knowledge for products. Specifically, collaborative relationships lead to interactive conflict resolution, involving brainstorming and problem-solving, that not only helps transfer an individual's knowledge into organizational collective knowledge, but also helps identify new TC opportunities in a market (Frishammar et al., 2012).

Collaborative leadership is a key factor in developing a successful cross-functional team for new product development, as emphasized in the extant research (Holland et al., 2000; Lank, 2006; Sivasubramaniam, Liebowitz, & Lackman, 2012; Souder & Sherman, 1993). Collaborative leadership is crucial for achieving NPD performance because of the structure of the collaborative NPD teams formed by a group of qualified individuals from diverse backgrounds and specialties. Potential problems such as conflicts of interest, contradictory goals, and poor information flow among members (Moenaert & Souder, 1990; Nakata & Im, 2010) often arise due to the nature of this type of arrangement and it is the responsibility of the leader in a cross-functional collaboration team to create an environment that provides open communication channels, encourages participation and sharing of information, and consolidates different opinions (Lank, 2006; Souder & Sherman, 1993). Such an environment will keep cross-functional team members motivated and sustain positive emotions that overcome attitude and stereotype barriers (Nakata & Im, 2010). Glaser (2004) identified various factors that impact collaboration team effectiveness, suggesting that team leaders should focus on leadership commitment, develop a vision and keep it in focus, attend to relationships, maintain open and collaborative communications and problem-solving mechanisms, structure the organization to deliver what is promised, and remain mindful of learning. Sivasubramaniam et al. (2012) conducted a rigorous meta-analysis to examine the effects of NPD team characteristics, and concluded that the team leadership has a significant and positive impact on NPD performance. However, there is no empirical evidence demonstrating that collaborative leadership affects TC performance.

Communicating and sharing information as a means of transforming various inputs into a cohesive final output is inextricably linked to the quality and performance of a cross-functional collaboration team (Glaser, 2004). Communication refers to the formal and informal sharing of meaningful and timely information between operations (Anderson & Narus, 1990). Lank (2006) provided several suggestions for ways to support effective communication within cross-functional collaboration activities, for example by taking the path of least resistance wherever possible, investing sufficient time and attention in communication and information-sharing processes, and ensuring that communication processes reach all key stakeholders while at the same time keeping the personal touch. Parker (2000) pointed out that collaboration implies communication and the sharing of information between two functions and that frequent communication is a key factor for a successful NPD process. Leenders, Kratzer, and Van Engelen (2003) also argued that the performance of new product creativity is generally shaped by coordinated communication among the members of a cross-functional team. This is also realized in the field; for example, the 3M Company has its own internal channels for communicating and sharing information, research data, and messages across different functional units to maximize the benefits of collaboration for TC. The ability to communicate and share information is crucial for the improvement of TC performance because it minimizes conflict and facilitates the cross-fertilization of ideas (Conceição, Hamill, & Pinheiro, 2000).

Trust formation is a social psychological process related to perceptions and is based on positive expectations of intentions held by one unit about another unit's capabilities, expertise, knowledge, motives, or intentions (Rousseau, Sitkin, Burt, & Camerer, 1998). Trust is formed by a long-term process that involves the growth of knowledge and an understanding of other team members through interactions. Past empirical results suggest that building trust is a necessary part of establishing a new product development team because it feeds collaborative product creativity (Bstieler, 2006). Effective collaboration requires a powerful catalyst, trust, between two units or employees (Zahra & Nielsen, 2002). Where there is no trust within a team, the team members will have difficulty in revealing their ideas thoroughly and integrating their resources, and will have confidentiality concerns and, consequently tend to keep the details to themselves, all of which are counterproductive for technology commercialization. Touhill, Touhill, and O'Riordan (2008) emphasized the importance of trust building, which they considered to be a critical step in the idea discovery phase of the TC process.

In summary, each of the four dimensions captures a unique set of characteristics, but taken together they reflect a more complete picture of the concept of cross-functional collaboration that impacts TC performance. This leads to the following hypothesis:

Hypothesis 1. Cross-functional collaboration is positively related to technology commercialization.

2.2. *Effect of cross-functional collaboration on knowledge creation*

When firms face complex product development challenges, they need the expertise provided by different functional units if they are to exchange information, generate new ideas, solve problems, and accomplish necessary tasks. Courtney (2001) elaborates on how organizations can create knowledge by applying Churchman's (1971) inquiry methods, which are designed to support cross-functional collaboration. For example, in R&D and marketing collaborative teams in high-tech industries, R&D engineers focus on product characteristics, techniques, and the exploration of new technologies while the marketing people seek to understand customers' needs by analyzing customer responses or monitoring competitors' activities and are responsible for finding potential new markets. Once a team of people from different backgrounds has been assembled and their different experiences and perspectives brought together, they must share knowledge and try to understand each other's functions and preferences. This integration process is a vital step that enables team members to move forward and create new knowledge (Calantone & Rubera, 2012; Grant, 1996).

Both academics and practitioners have discussed the relationship between cross-functional collaboration and knowledge creation. Mir and Rahaman (2003) used a case study to illustrate how a cross-functional team composed of a variety of functional departments (in this case, finance, operations, and marketing) creates knowledge, elucidating the knowledge creation process by following Nonaka's (1994) theoretical framework. They concluded that knowledge is created and enhanced through the formation of common trust, continuous dialogue, and frequent meetings among members of the cross-functional team to share implicit perspectives. Samaddar and Kadiyala (2006) suggested that the success of collaborative knowledge creation relies on increasing the rate of leaders' participation and choosing members who already have experience with working in collaborative teams. Back, von Krogh, Seufert, and Enkel (2005) used the company Chevron as an example to demonstrate the use of methods designed to increase cross-functional collaboration, including the use of networking mechanisms, establishing best practice databases, and encouraging the cross-fertilization of knowledge by putting together teams working on similar issues. Based on this literature and the real-world cases they present, the following hypothesis is proposed:

Hypothesis 2. Cross-functional collaboration is positively related to knowledge creation.

2.3. Effects of knowledge creation on technology commercialization performance

Knowledge is a strategic resource that provides added value to customers and leads to a sustainable competitive advantage (Grant, 1996). The ability to integrate knowledge (which may be domain-specific, procedural and/or general in nature) and to absorb and apply it to create new knowledge within an organization is considered the most important factor contributing to technology commercialization (Frishammar et al., 2012). As part of this process, organizations require both the creation of new knowledge and its integration with the existing knowledge coming from their daily operations at each stage of the TC process (Jolly, 1997) if they are to achieve good TC performance. Previous studies suggest that knowledge creation within an organization does indeed play a critical role in the success of commercialization (Mir & Rahaman, 2003; Mitchell & Singh, 1996). Knowledge creation can stimulate profit-generating new product development efforts and expand and enhance TC performance (Lin et al., 2006; Teece, 1998).

Drawing on Nonaka's (1994) SECI model (Socialization, Externalization, Combination and Internalization), we therefore sought to understand how knowledge creation enhances TC performance in the high-tech industry. Nonaka's SECI model describes how the processes of socialization, externalization, combination, and internalization combine to create continuous dialogue modes from implicit to explicit knowledge. Precisely how these four categories of knowledge creation affect TC activities is described below.

Socialization involves the conveying of implicit knowledge through frequent social interactions that help organizational members share experiences and thinking styles (Nonaka, Toyama, & Konno, 2000). Although the implicit knowledge related to high complexity tasks such as TC is harder to acquire than other routine operations, it is helpful if newcomers to the team who are in charge of commercializing new technologies keep in close contact with more experienced staff via a communication platform. This facilitates the socialization process and is particularly beneficial to the commercialization process (Cousins & Lawson, 2007; Mir & Rahaman, 2003).

Externalization refers to the conversion of implicit knowledge into explicit knowledge and the exchange of knowledge between individuals and a group. Externalization is sustained by the use of metaphors, analogies, stories and language rich in imagery (von Krogh, Ichijo, & Nonaka, 2000). Thorburn (2000) argues that the use of externalization can turn hidden implicit knowledge into explicit knowledge during the R&D commercialization process.

Combination is the process that transforms implicit knowledge into more complex and systematized explicit knowledge. The combination process, which consists of the information exchange among individuals and knowledge delivery among groups, generates new knowledge applications and enhances the firm's ability to commercialize new products and services effectively through intranet communication platforms and formal records in the organization (Lee & Choi, 2003). Mir and Rahaman (2003) recommended the creation of a supportive knowledge-conversion processes environment to accelerate the effective use of knowledge to support the commercialization process.

Internalization is the conversion of organization-wide explicit knowledge into the implicit knowledge of individual team members. Internalization derives from continuous organizational learning and the gathering of each person's own experience by learning-by-doing, on the job training, and learning by benchmarking. High quality learning mechanisms have been shown to improve the commercialization of new technologies (Zimmerman, 1982), allowing organizations to create new products at a lower cost and facilitating faster TC.

Combining the concepts of these four dimensions, we therefore propose the following hypothesis:

Hypothesis 3. Knowledge creation is positively related to technology commercialization performance.

2.4. The mediating effect of knowledge creation

We have focused on the direct impacts of cross-functional collaboration on technology commercialization performance, but based on KBV, knowledge creation also plays a pivotal role, albeit implicitly, between cross-functional collaboration and TC. Knowledge creation is not just knowledge per se, but as a dynamic process also encompasses the human interactions within an organization, with a social agenda that involves guiding the firm to take the necessary steps to ensure knowledge creation and product development performance (Takeuchi, 2013). For example, IBM Global Technology Services has established a coordinating team with members selected from different business units for product development. This team holds face-to-face meetings and crash courses on knowledge management regularly to accelerate the acquisition of specific-domain knowledge, thus creating new knowledge, improving the quality of decision making, and speeding up new product development (Back et al., 2005). De Luca and Atuahene-Gima (2007) concur, arguing that an effective knowledge mechanism enhances product innovation performance by improving the collective organizational learning across all the firm's functional units. This insight suggests that researchers should take a fresh look at the examination of these nomological relationships. Specifically, the constructs of cross-functional collaboration affect technology commercialization performance indirectly through their effect on knowledge creation, leading to the following hypothesis:

Hypothesis 4. Knowledge creation mediates the relationship between cross-functional collaboration and TC performance.

3. Research methodology

3.1. Sampling frame

This study employed a survey method to collect primary data from Taiwan's high-tech manufacturing companies. Cross-functional collaboration is especially important for Taiwan's high-tech companies due to the constant pressure for shorter time-to-market and price competition. The sample population for this study was the high-tech manufacturing firms located in Taiwan's Science Parks and listed in the most recently available list of the “Top 1000 Manufacturers in Taiwan” published annually by *CommonWealth* magazine. The use of location as an additional filter ensures that the firms are high-tech manufacturers, as by law only high-tech companies such as manufacturers of semiconductors, computers, telecommunication equipment, and optoelectronics can apply for space in the Science Park. The 895 high-tech manufacturing firms that qualified were then subjected to the following second-stage selection criteria: company age, size (in terms of employee number) and annual sales. To be included in our study, a firm must have annual sales of US$100 million or more, at least 100 employees, and have been in operation for at least 5 years in Taiwan. Small and medium enterprises (SMEs) were excluded because it is comparatively easier for SMEs to engage in internal collaborations because of their structure and size. One hundred and six of the 895 firms satisfied all the above criteria and were included in the survey.

3.2. Data collection, non-response bias and common method bias

Either the R&D manager or the marketing manager actively involved in TC was identified from each firm's website as our primary contact. We mailed 4 questionnaires to each company's primary contact and asked the manager to distribute the questionnaires (2 for R&D and 2 for Marketing, using a manager–employee pair format). In total, 424 questionnaires were sent to potential participants. Of the 207 responses received, four of them were incomplete, resulting in a 47.88% response rate and 203 valid data points. Of these respondents, 15.8% ($n = 32$) were from R&D managers/Chief Technical Officers (CTO), 12.8% ($n = 26$) were sales & marketing managers, 45.3% ($n = 92$) were R&D engineers, and 26.1% ($n = 53$) were sales & marketing staff. We recognized the difficulty and importance of finding respondents who can provide insights to various factors and so built in a selection filter by asking the participants to self-check against their experiences before taking the survey. We also asked about their experience in the survey for validation. The responses revealed that 85.7% ($n = 174$) of the participants were working on cross-functional teams related to at least five TC projects per year, while 82.3% ($n = 167$) of the participants worked on bringing new products to market at least five times per year. Since the primary focus of the present study is on organization behavioral factors, the respondents' abundant experience in this area should provide some valuable insights.

3.2.1. Non-response bias

This aspect was assessed by comparing the early (those who responded to the first mailing) and late respondents (those who responded after the reminder) in terms of annual sales and number of employees using t-tests. The results showed no statistically significant difference between these two groups, indicating that non-response bias did not present a problem for this study.

3.2.2. Common method bias

To reduce common method bias, Podsakoff, MacKenzie, Lee, and Podsakoff (2003) suggest the use of specific procedures during both the design and data collection processes. Following these guidelines, we protected respondent–researcher anonymity, provided clear directions to the best of our ability, and proximally separated independent and dependent variables (Podsakoff et al., 2003). We then tested for bias statistically. Harman's one factor test (Brewer, Campbell, & Crano, 1970; Greene & Organ, 1973; Harman, 1960) was used to determine whether common method bias would pose a threat to the validity of this study's results. The unrotated factor solution indicated that no factor accounted for 50% or more of the variance, which suggests that common method bias is unlikely to be a significant threat to the validity of this study.

3.3. Measures

All items were adapted from the literature and modified as needed for this study (see Appendix A). All items used a five-point Likert scale (ranging from 1 = "not at all important" to 5 = "very important").

3.3.1. Cross-functional collaboration

This study used cross-functional collaboration as an independent variable and measured its four dimensions: collaborative relationship, collaborative leadership, communicating and sharing information, and trust formation. We asked participants to rate the importance of each statement describing their CFC in these four categories.

3.3.2. Knowledge creation

Based on the definition of knowledge creation, we operationalized the notion of knowledge creation by using the way knowledge activities worked in practice in a firm (Nonaka, 1994; Nonaka et al., 2000; Teece, 1998), specifically the extent to which the firm uses knowledge creation activities (i.e., socialization, externalization, combination and internalization) to generate new knowledge. For example, for the socialization process of knowledge creation, we asked our participants "Have you ever been involved in knowledge activities such as a mentoring program, employee rotation, or brainstorming meetings across different departments?"

3.3.3. TC performance

Based on the definition provided by Jolly (1997), TC is the process that begins with acquiring a new idea or technical breakthrough, incubating it to define commercializability, demonstrating its use contextually in products and processes, promoting adoption, and ultimately sustaining the product's long-term presence and value on the market. We operationalized TC performance by identifying the perceived outcomes from each stage of TC. In the early stages (i.e., imaging, incubating, and demonstrating), there is a growing need to rapidly discover the awareness of the technology (or existing patents) both inside and outside the business. Once ideas have been discovered, the members working on the projects should discuss how best to commercialize them. Thus, the effective use of patents and know-how can be used to measure TC performance in early stages (Jolly, 1997; Li, Guo, Liu, & Li, 2008). The number of new products, time to new product, and market futures can also be used to evaluate TC performance in the later stages (i.e., promoting and sustaining) (Jolly, 1997; Li et al., 2008; Zahra & Nielsen, 2002).

4. Data analysis and results

Given our research model and objectives, SEM enjoys several advantages over other analysis techniques such as linear regression because SEM can examine proposed causal paths among constructs (Gefen, Rigdon, & Straub, 2011). We analyzed the data using IBM Amos 20 (Arbuckle, 2011).

4.1. Descriptive statistics, reliability and validity

Table 1 presents the means, standard deviations, Cronbach's alphas, AVEs and construct correlations. The Cronbach's alphas (ranging from .73 to .76) indicate a satisfactory degree of internal consistency reliability for the measures (Bollen & Lennox, 1991), with all values well above .70 (Nunnally & Bernstein, 1994). Construct reliability was assessed based on the composite construct reliabilities, computed using the formula: $\rho = (\Sigma\lambda i)^2/((\Sigma\lambda i)^2 + \Sigma\theta i)$, where λi refers to the ith factor loading and θi refers to the ith error variance (Hair, Black, Babin, & Anderson, 2010, p. 687). As shown in Table 1, the composite reliability ranged from 0.93 to 0.98, well over the commonly accepted cut-off value of .70 (Hair et al., 2010), thus demonstrating the adequate reliability of the measures.

Discriminant validity was first assessed by examining the factor correlations. Although there are no firm rules, inter-construct correlations below |.7| are generally considered to provide evidence of measure distinctness, and thus discriminant validity (Ping, 2003). None of the factor correlations were greater than .7, which demonstrates discriminant validity (see Table 1). Another way to examine discriminant

Table 1
Descriptive statistics and correlations.

Variable	Mean	S.D.	Cronbach's alpha	Composite reliability	CR	CL	CSI	TF	S	E	C	I	TNP	FT	MF	PK
CR	4.11	0.6	0.76	0.97	0.91											
CL	4.07	0.6	0.74	0.97	.27**	0.91										
CSI	4.18	0.57	0.73	0.97	.18**	.36**	0.92									
TF	4.08	0.67	0.75	0.96	.20**	.24**	.36**	0.88								
S	3.55	0.67	0.75	0.95	0.05	0.05	.22**	0.01	0.87							
E	3.72	0.64	0.75	0.95	.17*	.25**	.20**	0.08	.32**	0.86						
C	4.05	0.62	0.74	0.95	0.06	0.07	.26**	0.08	.35**	.23**	0.87					
I	4.06	0.57	0.75	0.97	0.05	.37**	0.12	0.07	.24**	.39**	.45**	0.92				
TNP	3.58	0.53	0.75	0.93	−0.13	0.02	0.12	0.09	0.05	−0.01	0.11	−0.02	0.82			
FT	4.03	0.56	0.76	0.95	−.16*	.16*	.34**	0.14	0.09	0.031	.17*	.15*	.32**	0.9		
MF	4.11	0.51	0.74	0.97	0	.24**	.23**	0.09	0.1	−0.05	0.13	0.09	.29**	.41**	0.91	
PK	4.22	0.56	0.75	0.98	−0.07	0.03	.19**	0.11	0.11	−0.07	.23**	0.09	.34**	.46**	.41**	0.92

Note: N = 203; AVEs on diagonal.
CR: collaborative relationship; CL: collaborative leadership; CSI: communicating and sharing information; TF: trust formation; S: socialization; E: externalization; C: combination; I: internalization; TNP: the amount of new products; FT: faster time to new product; MF: market future; PK: effective use of patent and know-how.
* $p < 0.05$.
** $p < 0.01$.

validity is to compare the average variance extracted (AVE) to the squared inter-construct correlation. When the AVE is larger than the corresponding squared inter-construct correlation estimates, this suggests that the indicators have more in common with the construct that they are associated with than they do with other constructs, which again provides evidence of discriminant validity (Kline, 2010). The data shown in Table 1 suggests the adequate divergent validity of the measures.

4.2. Exploratory factor analysis

For the measurement property evaluation, exploratory factor analysis (EFA) was conducted to explore the factor structure. Before performing the factor analysis, we first verified that the data were appropriate for factor analysis using two tests: the Kaiser–Meyer–Olkin (KMO) test and the Bartlett sphericity test. The result of both tests indicated that a factor analysis would be useful given our data. The initial factor analysis using principal components analysis extracted four factors that were evident on the scree plot, all with an eigenvalue greater than one. Factor loadings for the cross-functional collaboration block ranged from 0.55 to 0.71, the knowledge creation block ranged from 0.61 to 0.69, and the TC performance from 0.53 to 0.68. Overall, the results for EFA achieved standard factor loadings of 0.5 as the cut-off significance, confirming that individual factors can be identified in a given block of dimensions.

4.3. Measurement model

A measurement model was then analyzed to assess the measurement quality of the constructs using a confirmatory factor analysis (CFA). The measurement model consisted of three latent factors (cross-functional collaboration, knowledge creation, and TC performance) and 12 indicators. The loading ranges for the four cross-functional collaboration factors were as follows: collaborative leadership, .66 to .77; collaborative leadership, .41 to .99; communicating and sharing information, 63 to .76; and trust formation, 55 to .83. The loading ranges for the four knowledge creation factors were as follows: socialization, .49 to .80; externalization, .58 to .75; combination, .60 to .63; and internalization, .38 to .99. The loading ranges for the four technology commercialization performance factors were as follows: the number of new products, .52 to .67; faster development of new products, .60 to .84; future market potential, .48 to .82; and effective use of patents and know-how, .50 to .84. The model chi-square was statistically significant (χ^2 (563) = 960.717, $p < .000$), which indicates that the exact fit hypothesis should be rejected. However, this test is highly sensitive (Jöreskog & Sörbom, 1986) so other measures of goodness-of-fit were also examined. The comparative fit index (CFI) was .820, which exceeds the cutoff value of .80 (Hair, Anderson, Tatham, & Black, 2009), and the standardized root mean square residual (SRMR) was .0662, which is less than .08 (Hu & Bentler, 1999). The root mean square error of the approximation (RMSEA) is .059, which is less than .08 (Byrne, 2001). Thus, we concluded that our data adequately fit the measurement model.

4.4. Structural model

After confirming adequate fit for the measurement model, we assessed the fit of our structural model. The goodness-of-fit of the structural model was comparable to that of the previously described CFA model. The hypothesized model appears to fit to the data well, as shown in Fig. 2. We did not conduct post-hoc modifications because of the good fit of the data to the model. Based on this evidence of acceptable fit, we then moved on to test our hypotheses.

4.5. Hypothesis testing

The four hypotheses presented earlier were tested collectively using the structural equation modeling (SEM) approach and IBM Amos 20 (Arbuckle, 2011). Each indicator was modeled in a reflective manner; the three latent variables were linked as hypothesized. Model estimation was performed using the maximum likelihood technique. We chose maximum likelihood parameter estimation over other estimation methods (e.g., weighted least squares, two-stage least squares) because the data were fairly normally distributed (Kline, 2010). As shown in Fig. 2, all paths were significant at the .05 level or better.

Hypothesis 1 posited that greater levels of cross-functional collaboration would result in higher levels of technology commercialization; our results support Hypothesis 1 ($\beta = .35$, $t = 2.824$, $p < .001$). Hypothesis 2 posited that greater cross-functional collaboration would promote higher levels of TC performance; our results also support Hypothesis 2 ($\beta = .30$, $t = 2.39$, $p < .05$). Hypothesis 3 stated that greater levels of knowledge creation would promote higher levels of technology commercialization; once again, our results support Hypothesis 3 ($\beta = .24$, $z = 2.10$, $p < .05$).

Hypothesis 4 stated that knowledge creation would mediate the relationship between cross-functional collaboration and technology commercialization. Researchers often conduct mediation analyses in order to indirectly assess the effect of a proposed cause on some outcome through a proposed mediator (Preacher & Hayes, 2004). A mediator (in this case, knowledge creation) is an intervening variable that transmits the effect of an independent variable (cross-functional collaboration) to a dependent variable (technology commercialization).

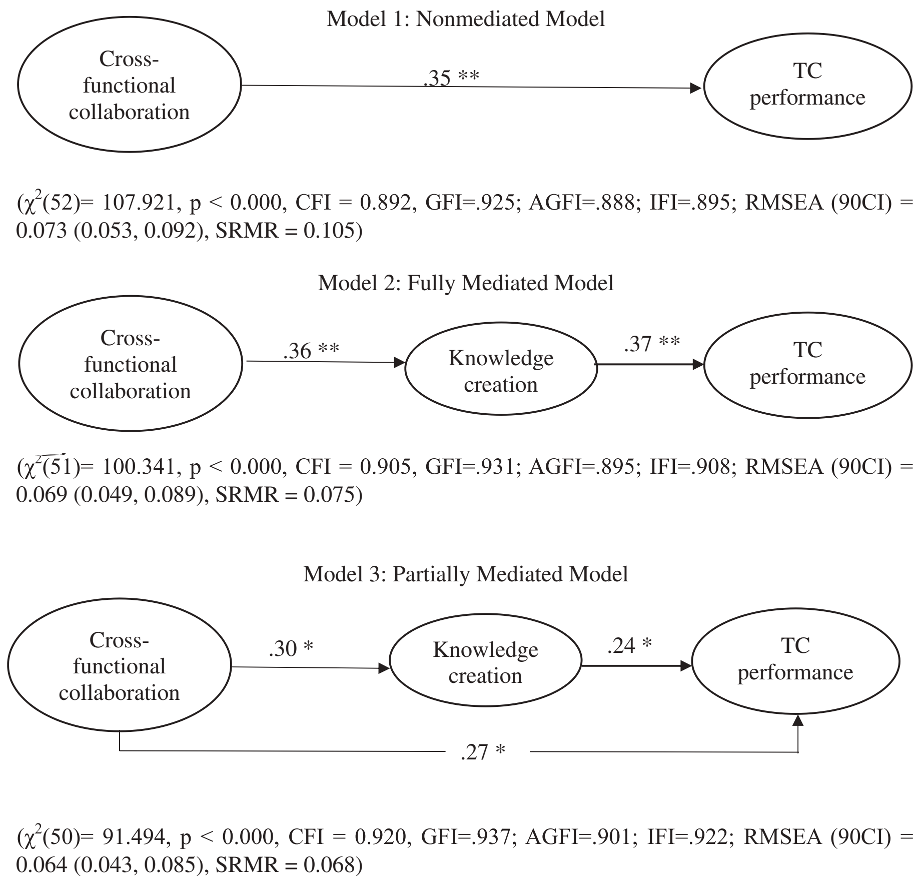

Fig. 2. Mediation models.

Mediation may be full or partial. Full mediation describes the case where the independent variable no longer affects the dependent variable when controlling for the mediating variable, i.e., there is no longer a direct effect from the independent variable to the dependent variable. In the case of partial mediation, the strength of the path from the independent variable to the dependent variable is reduced but is still statistically significant when the mediator is introduced. To illustrate this discussion in the context of our study variables, examples of full, partial, and no mediation models are presented in Fig. 2.

The results of our comparison of the aforementioned models are presented in Table 2. We compared the partial mediation model to the full mediation model, as well as the partial mediation model to the direct (no mediation) model. The fit of the partially mediated model is clearly better than the fit of the full mediation model ($\Delta\chi^2 = 8.847$, $\Delta df = 1$, $p < .000$) or the no mediation model ($\Delta\chi^2 = 16.427$, $\Delta df = 2$, $p < .000$). As the partial mediation model provides the best fit, our data suggest a partially mediated relationship (Kline, 2010). As such, Hypothesis 4 is supported and we concluded that knowledge creation does indeed partially mediate the relationship between cross-functional collaboration and technology commercialization. Hence, cross-functional collaboration has a direct effect on technology commercialization performance in addition to its indirect effect via knowledge creation.

5. Discussion

The central theme of this research is to advance our understanding of the way cross-functional collaboration enables high-tech firms to enjoy better TC performance and identify opportunities through the creation of new knowledge. The empirical evidence collected for this study supports our three key findings. First, we found that the impacts of cross-functional collaboration positively affect TC performance. This implies that an increase in cross functional collaboration integration supports the more effective use of patents and know-how, accelerates new product development, increases the number of new product releases, and contributes to the development of more future-oriented products, with the ultimate result being superior TC performance. Second, the data indicate that knowledge creation positively correlates with TC performance. This result is in accord with the views expressed by other researchers (e.g., Mir & Rahaman, 2003; Thorburn, 2000), and suggests that facilitating knowledge creation is likely to enhance TC performance. Finally, our results confirmed that cross-functional collaborations in high-tech firms indirectly influence TC performance, an impact that is partially mediated by the effect of knowledge creation. These findings contribute to the growing interest among both academics and managers in understanding how best to facilitate successful technology commercialization, particularly by

Table 2
Mediation test.

Model	χ^2	df	Sig	$\Delta\chi^2$	Δdf	Δsig	CFI	SRMR	RMSEA (90%CI)
Partial mediation	91.494	50	<.00	–	–	–	0.920	0.068	0.064 (.043, .085)
Full mediation	100.341	51	<.00	8.847	1	<.000	0.905	0.075	0.069 (.049, .089)
No mediation	107.921	52	<.00	16.427	2	<.000	0.892	0.105	0.073 (.053, .092)

Note: The partial mediation model served as the baseline for chi-square difference testing; N = 203.

building cross-functional collaboration teams with a high capacity for knowledge creation. Based on these findings, we offer some insights regarding theoretical and managerial implications in the remainder of this section.

5.1. Theoretical implications

This study has important theoretical implications for research into cross-functional collaboration, knowledge creation, and technology commercialization. Most previous studies (e.g., De Luca & Atuahene-Gima, 2007) have modeled cross-functional collaboration as a one-dimension construct, but such an approach may unintentionally overlook other important facets of cross-functional collaborations. For example, leadership and trust were absent from De Luca and Atuahene-Gima's (2007) scale describing cross-functional collaboration. To capture cross-functional collaboration more fully, we integrated previous studies and then conceptualized, operationalized, and measured cross-functional collaboration as a reflective construct with four dimensions, collaborative relationships, collaborative leadership, communicating and sharing information, and trust formation. This conceptualization is the first step towards building a much needed body of knowledge on cross-functional collaboration and provides researchers a useful lens through which to examine the effectiveness of cross-functional collaborations in supporting other industrial activities.

Second, a theoretical basis for the relationship between cross-functional collaboration and TC performance was elucidated by adopting the knowledge-based view (Grant, 1996; Kogut & Zander, 1992). Our results demonstrated how knowledge creation matters in TC performance by focusing on its mediating role. This implies that knowledge creation can transfer the effect of cross-functional collaboration into TC performance. This study extends previous findings that support the use of the KBV in TC activities. Prior studies have encouraged managers to either integrate prior, domain-specific, and general knowledge (Frishammar et al., 2012) or to develop a knowledge integration mechanism (De Luca & Atuahene-Gima, 2007) to enhance TC and NPD performance, assuming that the integration of knowledge is the key driver for TC or NPD performance. Knowledge creation theory contends that knowledge creation is a synthesizing process (made up of socialization, externalization, combination and internalization) that can be applied to deal with complicated information across different interfaces in the organization (Nonaka & Toyama, 2003). This insight implies that we could view cross-functional collaboration teams as a knowledge-creating entity that allows team members to solve the conflicts collectively, to generate new knowledge by learning from conflicts and, ultimately, to improve the firm's performance. This view is particularly applicable in the context of TC in high-tech firms, and leads to a better understanding of how the dynamic interactions among individuals or cross-functional work groups function in term of knowledge creation and, in turn, impact the commercialization of the technologies. To the best of our knowledge, this current study is the first to show that knowledge creation is indeed a mediator between cross-functional collaboration and TC performance. Also, a more grounded understanding of knowledge creation theory in an organization may fuel the next leap in knowledge in the area of TC research.

Third, our results show that knowledge creation and cross-functional collaboration are important success factors for TC performance. The current study extends previous findings (e.g., Mir & Rahaman, 2003; Zahra & Nielsen, 2002) in terms of collaboration and knowledge perspectives. Previous work has suggested that an effective integration mechanism is a significant moderator of the relationship between firms' resource and TC (Zahra & Nielsen, 2002). However, no specific mode of collaboration has been identified to be a particularly effective means of improving TC performance. The case study presented by Mir and Rahaman (2003) showed how firms can improve their commercialization performance by creating an organization-wide collaborative working environment that facilitates new knowledge creation and information sharing. Although they described significant relationships among cross-functional collaboration, knowledge creation, and commercialization, empirical work supporting this path is still urgently needed. We cannot stress too strongly how important it is for a firm to have an organizational collaboration mechanism in which cross-functional collaborations and knowledge creation mechanisms work side-by-side to enhance TC effectiveness.

Finally, the measurement for TC performance was improved by adopting Jolly's (1997) process-oriented TC view, which contends that the evaluation of TC performance is inextricably linked with the development process. Jolly divided the TC process into five steps and provided expected outcomes for each. By integrating this process-oriented view with the findings of previous studies (Li et al., 2008; Zahra & Nielsen, 2002), we conceptualized, operationalized, and measured the construct of TC performance as a higher-order construct reflected by the number of new products, the speedier development of new products, potential future market, and the effective use of patents and know-how to provide researchers with a better way to measure TC performance and thus examine other antecedents of successful TC.

5.2. Managerial implications

The benefits obtained by linking cross-functional collaboration and the commercialization of new technologies have been widely acknowledged and appreciated by high-tech industries. For practitioners charged with managing cross-functional collaboration teams for TC projects, this study not only provides support for the use of knowledge creation as an effective mechanism, but also offers the following suggestions for practitioners.

High-tech firms can significantly improve the return on their technology commercialization investment by establishing a wide range of knowledge creation activities in their cross-functional collaboration teams. Managers can bring the organizational routines developed in their own units to serve as knowledge creation mechanisms in cross-functional teams. For example, marketing team members might have the marketing expertise and knowledge, a broad vision of product development, a good understanding of market competitors and an awareness of the market dynamics, while the R&D team members are likely to be more familiar with the science and technology, as well as having a broader operational understanding, and better control of the R&D performance. Both teams need to work closely together with the help of knowledge creation methods such as mentoring programs, learning by doing, and rotating employees across different departments. By doing so, cross-disciplinary knowledge is progressively generated that can help refine and redefine technologies and products, uncover new ways to look at the market, and substantially contribute to a firm's overall performance.

In the early stage of building a cross-functional collaboration team tasked with accomplishing TC, team leaders should focus on developing collaborative leadership and trust formation (Bstieler, 2006; Lank, 2006). Knowledge generation in the TC process must accumulate as a result of the formation of mutual trust among team members, and a shared implicit perspective through continuous dialogue and regular meetings. The role of the leader in a cross-functional collaboration is to serve as a catalyst to help organize the group and build effective communications among team members. Individual team members play their part by exponentially increasing information sharing, thus leading to improved TC performance.

5.3. Limitations, future research and conclusion

This study suffers from a number of limitations. First, the generalizability of the results is limited, because data were only collected from a sample consisting of Taiwan's high-tech manufacturers. Second, given its exclusive focus on intra-organizational technology commercialization, these results may not be applicable to the context of external technology commercialization. Third, our exclusive concentration on intra-organizational knowledge is a further limitation. Other external knowledge, including important factors such as market knowledge and customer knowledge that also affect TC performance, won't be considered here. Finally, our tight focus on organizational behavior factors that have an impact on cross-functional collaborations is also a limitation. This study did not consider environmental factors.

In response to the limitations of the current study, we offer some suggestions for future research. First, our study brings an international perspective to TC research in the literature. The conceptual framework of management research will undoubtedly benefit from further investigations in a variety of contexts to eliminate both language and cultural barriers. Given that most of the TC studies conducted to date have been performed in the U.S. or other developed countries, there is clearly a need for a cross-functional collaborative-oriented TC model that pays attention to companies located in high-tech Science Parks in developing countries, such as Zhongguancun Science Park in China and Bangalore IT Park in India for comparison.

Second, many firms acquire technological knowledge or patents from external sources to complement their internal R&D activities. External technology commercialization (ETC) is a proactive trend in practice, but it lacks a theoretical foundation. This raises an interesting research issue: does the knowledge-based view provide adequate theoretical anchors for studies examining how a knowledge creation mechanism can be used in external collaborations and partnerships in the context of ETC?

Third, our findings have confirmed that there is an effect due to cross-functional collaborations on TC performance and revealed the mediating role of knowledge creation. Researchers now need to examine other factors that may be a moderating or mediating role for this path. Several internal or external environmental factors have yet to be examined before we can establish a comprehensive body of knowledge in TC research, for example the potential role of top management behavioral integration as a moderator or mediator (Simsek, Veiga, Lubatkin, & Dino, 2005). Also, other knowledge-related factors should be considered as potential mediators, including external knowledge creation (e.g., knowledge from suppliers, customers, competitors and governments) (Nonaka & Toyama, 2003). The inclusion of these factors would extend the scope of KBV from with organizations to encompass the way organizations interact with external factors in TC research.

Finally, this study focuses exclusively on the organizational behavior perspectives of the cross-functional collaboration construct, thus excluding other potentially important perspectives, such as the role of information technology (IT) or information systems (IS). For example, the way IT is implemented in a cross-functional collaboration might play a pivotal role that supports knowledge generation and the TC process. Few studies have yet been conducted in the field of NPD (Datta, 2012; Song & Song, 2010), but a follow-up project that investigates the effect on this path in more depth is clearly needed.

In conclusion, our primary research objective was to unravel the relationships among cross-functional collaboration, knowledge creation and TC performance. We found that cross-function collaboration may indeed reveal new opportunities for creating organizational knowledge and commercializing technologies and we confirmed that knowledge creation plays an important mediating role in the relationship between cross-functional collaboration and TC performance. These findings challenge researchers and managers to rethink how and why cross-functional collaboration affects TC performance through the lens of KBV, specifically by considering knowledge creation. Consequently, the contributions of this study provide new insights into industrial marketing literature by proposing a cross-functional collaboration-enabled TC model that takes into account the effect of knowledge creation.

Acknowledgments

The authors would like to acknowledge the financial support which was provided to this study by the NSC 100-2410-H-024-014.

Appendix A. Measurement

Cross-functional collaboration

Collaborative relationships (Back et al., 2005; Ettlie, 1995; Mitchell & Singh, 1996)

- A decision-making methodology that is well understood with clearly assigned roles and responsibilities commensurate with cross-functional team to take action
- Establishing an integrated mechanism to encourage the cooperation of different departments
- Evaluating the achievements of cross-functional teams more critically

Collaborative leadership (Glaser, 2004; Lank, 2006)

- Reconcile different views and build a consensus.
- Articulate and promote a shared vision.
- Balance the strategic and the operational.
- Encourage and inspire others.
- Deal comfortably with ambiguity and complexity.

Communicating and sharing information (Lank, 2006)

- Maintain open and collaborative communications and problem-solving mechanisms.
- Take the path of least resistance wherever possible.
- Invest sufficient time and attention in communication and information-sharing processes.
- Ensure that communication processes reach all key stakeholders.

Trust formation (Bstieler, 2006)

- The collaborative team members were frank in dealing with others.
- Promises made by collaborative team members were reliable.
- If problems arose, the collaborative team members were honest about the problems.

Knowledge creation (Nonaka, 1994; Nonaka et al., 2000; Teece, 1998)

Socialization

- The development of mentoring programs to transfer knowledge
- Employee rotation across different departments
- Brainstorming meetings

Externalization

- Modeling based on analogies and metaphors
- Problem-solving tips and experience converted to documents
- Capture and application of expert's knowledge

Combination

- Using the databases to acquire the best practice
- Using an intranet platform to share working knowledge
- Completely convert to records the firm's policy and working process instructions

Internalization

- On-the job training
- Learning by doing
- Learning by benchmarking

Technology commercialization performance (Jolly, 1997; Li et al., 2008; Zahra & Nielsen, 2002)

The number of new products

- Enriching and introducing variations to products
- Designing products based on customers' needs
- The kinds of products are numerous and complete.

Faster time to new product

- The speed with which new concepts and techniques are used in new products
- The speed from entry to the market to being known by customers.

Market future

- Compared with other competitors, our new products have more market share.
- Compared with other competitors, our new products have more annual sales.
- The product life cycle of the new products in the market

Effective use of patents and know-how

- The capability of the integrated technology
- The technology is professional and variable and is not simulated by the competition.
- The number of new patents
- The ability to using different technology in the new product

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Yichen Lin serves as a professor in the Department of Business and Management, National University of Tainan, Taiwan. She has published several journal papers and participated in many industrial projects, especially in the areas of B to B marketing, marketing of high-tech products and R&D management. She also got the outstanding paper award for Industrial Marketing Management in 2006.

Yichuan Wang is a Ph.D. student in Management Information Systems at Auburn University. He received his B.B.A. degree from the National Chung Cheng University and a M.S. degree from the National University of Tainan. His research interests include healthcare information technology, social media analytics and IT-enabled innovation and business value. His research has appeared in various journals, such as Industrial Marketing Management, International Journal of Production Economics, International Journal of Information Management, Informatics for Health and Social Care, and International Journal of Market Research.

LeeAnn Kung is an Assistant Professor in the Department of Marketing/Business Information Systems at Rowan University. Her research interests are in information systems and organization performance, organization improvisational capability, Qualitative Comparative Analysis Method, Healthcare IT, innovations diffusion, and Big Data value. Her research has appeared or forthcoming in several journals, such as Journal of Information Technology, Industrial Marketing Management, Journal of Enterprise Information Management, Journal of Information Systems Education. She earned her Ph.D. in Management Information Systems from Auburn University, her Master of Information Science from University at Albany, SUNY, and her MEd from National Louis University.