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Social networks, technology ties, and gatekeeper functionality: Implications for the performance management of R&D projects

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ABSTRACT

R&D project teams concerned with efficiency under limited resources must cohesively coordinate cooperation, interactions, and the exchange of ideas to sustain innovation. This research investigated the management of social networks, technology ties, and gatekeeper functionality from a networking perspective and examined their contribution to R&D performance, which was evaluated using data envelopment analysis. This study verified the relationships by using data from the Taiwan National Telecommunication Program, which coordinates more than 100 R&D teams in pursuing next-generation broadband technologies. The results regarding these relationships varied. The density of social networking and the outward- and novel-oriented gatekeeper functionality of a project team was found to significantly promote its R&D performance, whereas the density of technology ties exhibits no significance. Accordingly, this paper presents strategic implications for the management of projects, team interorganizational linkages, and governmental subsidy policies, and discusses the networking activities of R&D teams at the project level.

1. Introduction

Emerging market countries such as South Korea, Taiwan, China, and India have not yet reached developed country status, but have outpaced their developing counterparts (Bożyk, 2006). Some of these countries, such as South Korea, have initiated national programs to advance their technological capabilities to the level of those of developed counties (Lee et al., 2009; Mathews, 2006). Taiwan has launched national technology programs such as the National Telecommunication Program (NTP) to encourage frontier research and development (R&D) of technologies and achieve a globally competitive advantage. However, individual NTP academic projects have performed inconsistently and, therefore, raised practical concerns regarding the quality of project management and the efficiency of resource allocation, particularly under limited R&D resources (Hung and Shiu, 2014). Hung et al. (2010) revealed that several top-tier NTP research groups are centered around particular research institutions or universities, indicating that being part of a high-density research network can produce exceptional R&D performance. Links to local development centers absorb a large amount of resources; complementary technologies seem to be critical to scientific researchers (Tiwana, 2008).

According to Stewart and Barrick (2000), interpersonal skills and relationships mediate the contributions within a research team and affect performance. Coleman (1988) argued that a strongly connected relationship network resembles social capital. Specific capital of this type supports combinatorial innovation, transformative capacity, and knowledge integration in a cooperative team (Obstfeld, 2005; Tiwana, 2008), and channels resources toward the project team leader's network connections (Kao and Shen, 2009). The depth of a social network reflects the importance of a person acting as the information or knowledge source within his or her associated organization or society (Björk and Magnusson, 2009; Tsai, 2001). Centrality involves a high degree of inflow and outflow relationships in a network, and positively relates to the absorptive capacity of a team, attracting more R&D expenditure (Björk and Magnusson, 2009; Chiu, 2009; Tsai, 2001). The higher the centrality of a team within its organization or society, the more the team shares technologies through the networking process and contributes to innovation (Björk and Magnusson, 2009). Beyond its importance in social networks, the gatekeeper of an R&D team serves as an important communication channel and discriminates R&D performance (Hung et al., 2013). Allen (1977) asserted that the role of a gatekeeper is to actively acquire external information sources to meet information requirements and maintain a high level of communication, both within and outside of his or her organization. Gatekeepers are usually accomplished

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performers who produce more papers for presentation and publication and receive more recognition from their peers (Shumsky and Pinker, 2003). Furukawa and Goto (2006) asserted that corporate scientists with high numbers of publications serve as central conduits for the in-flow of knowledge from outside of their companies, thereby stimulating innovation. Consequently, social network and gatekeeper functionality accumulates technology ties, which involve dense technological connections within a network, leading to advantages in knowledge transfer and sharing (Lin et al., 2010). This process enhances technological development capability (Coleman, 1988). The cohesion theory indicates that benefits result from dense technology networks because of deep accumulative experience and intensive interactions (Coleman, 1988). Therefore, the purpose of this study is to examine the multifaceted influence processes of social networks and gatekeeper functionality mediated by technology ties to R&D project performance and thereby explain the performance discrepancy of R&D projects.

However, this study has a further academic concern. According to the perspectives of Granovetter's weakly tied networking (Granovetter, 1973) or Burt's structural holes (Burt, 2004), a highly closed network cannot encourage innovation; nevertheless, Hansen (1999) argued that weak ties aid a project team in searching for useful knowledge from others but impede the transfer of complex knowledge, which tends to require a strong tie between two parties. Hung and Shiu (2014) also reported that researchers' international educational backgrounds resemble the weakly tied linkages or structural holes that are described by Burt (2004), but they cannot support knowledge acquisition and dissemination for enhancing R&D performance. Therefore, to pioneer basic, large-scaled, and advanced technology programs, it is necessary to examine the contribution of strongly tied project organization to R&D performance. Furthermore, a social network's centrality often evolves a distinct mechanism in sharing technology, from which it forms strong technology ties among actors (Lin et al., 2010). Could such a deep technology paradigm enhance or inhibit R&D performance in the case of a national technology program for pursuing advanced technological frontier (Leonard-Barton, 1992)? Finally, is building the gatekeeper functionality of a project team still important in the current Internet era, in which people appear to have equal access to open information networks (Whelan et al., 2010)?

The paper is structured as follows. First, literature about social networks, technology ties, and gatekeeper functionality is reviewed to derive related hypotheses for examining the relationship between, and performance of, these three constructs. Next, this paper addresses the methodology for measuring R&D performance. This reveals a proposed multicriteria approach and related independent and dependent proxy variables. Third, the collected NTP data are analyzed using a partial least squares statistical method. Finally, the findings and discussion of the results demonstrate the empirical, practical implications and academic contributions, and avenues are identified for future research.

2. Theory and hypothesis

2.1. Social networks and performance

Wasserman and Faust (1994) defined a social network as a finite set or sets of actors and the relationship or relationships between them. The interrelations of actors may involve friends, relatives, classmates, and colleagues, and each actor establishes his or her own style of social networking (Argyle, 1998). Additionally, the social network influences his or her life, work, and emotional state, and may also affect the atmosphere, communication, and operational efficiency of an organization (Argyle, 1998). Moreover, dense networks tend to be loci of shared knowledge, language, and style, thereby facilitating communication and innovation (Walker et al., 1997; Nahapiet and Ghoshal, 1998). Densely embedded networks with numerous connections are identified as being advantageous, in so far as these networks are "closed" (Coleman, 1988). Networks that are dense and cohesive are conducive to mobilized action because interests and perspectives are prealigned, and the language and trust necessary to mobilize those interests are readily available (Obstfeld, 2005). Even though Burt's structural holes under weakly tied networks often led to novel ideas and explorative opportunities (Burt, 2004; Gilsing et al., 2008; Zaheer and Bell, 2005), there was no evidence that those ideas led to implementation efforts, let alone implementation success. Thus, the advantages of communication and accessibility pertaining to distinctively closed social networks should be emphasized, especially when conservatively addressing the efficiency of resource transformation under limited R&D resources. Burt's structural holes theory focuses on the emergence of novel ideas and market transactions resulting from a sparse network (Walker et al., 1997; Obstfeld, 2005), presenting a *tertius gaudens* (third who laughs) strategy in which a broker positioned between two disconnected parties can take advantage of the opportunities generated by being situated between the two parties (Vernet, 2012). Contrarily, the *tertius iungens* (third who joins)–oriented network is a strategy in which users connect people in their social network by either introducing disconnected individuals to each other or facilitating new coordination between connected individuals. This joining activity forms a friendly union that enhances the efficiency of implementation, such that the combinative activity involves both parties in fundamental cooperative innovation on an ongoing basis as the project unfolds (Obstfeld, 2005). Thus, when an organization manager is searching for a new market opportunity (the target), a *tertius gaudens* strategy such as the identification of a structural hole suggested by Burt is necessary to match the proper parties. Contrarily, after targeting a certain goal, a *tertius iungens* strategy is necessary to coordinate the connected people to produce coordinated actions that lead to innovation (Björk and Magnusson, 2009; Lingo and O'Mahony, 2010; Vernet, 2012). This research focused on the implementation problems of a national technology program involving basic research toward the given target and found that a *tertius iungens* networking strategy is preferable for increasing the density of the researchers' social network.

The power of social networks on innovation results from a set of resources including information, technological patents, experience, and financial capital that each actor within the social network possesses (Kilduff and Tsai, 2003). Lawler and Yoon (1998) argued that exchanges within the social network increase personal motivation to form affectionate and cohesive relationships. The degree of affection between people within the social network reflects mutual understanding and trust (Higgins and Kram, 2001). Lack of trust hinders sharing knowledge, combining skills, and making large joint investments, increasing the likelihood of being unproductive (Coleman, 1988). Trust in social relationships facilitates interaction (Chen and Wang, 2008) and enhances personal career success (Argyle, 1998). Hansen (1999) argued that a strong tie between two parties is necessary for the sake of complex knowledge transfer, which tends to be impeded in a weakly tied relationship. Guanxi, the Chinese social network, helps people exchanging resources and breeding trust within Chinese cultural contexts (Lin et al., 2012). Furthermore, trust increases the inclination of team partners to share information and knowledge (Collins and Smith, 2006) and allows them to use organizational resources efficiently and flexibly when encountering unexpected obstacles (Stewart and Barrick, 2000). Thus, dense and cohesive networks, repeated interactions, and the exchange of ideas are crucial to the coordinated actions necessary for sustained innovation efforts (Ahuja, 2000; Uzzi, 1997). Moreover, a dense network increases the probability

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of the development and transference of tacit knowledge and intangible resources that usually have a positive impact on innovative performance (Koka and Prescott, 2008). A dense network gradually established its identity to attract more resources (Kao and Shen, 2009; Moran, 2005). Particularly, when facing competitive uncertainty, dense interpersonal relationships between organization leaders lead to maintaining the power to access necessary resources (Westphal et al., 2006). Therefore, to succeed in a knowledge cluster, striving for more central network positions is imperative (Chiu, 2009). Suarez (2005) asserted that dense networking organizations promoted more rapid consolidation among technology competition, avoiding a long, stagnant resource-consuming explorative process.

The following hypothesis on the relationship between social networks and R&D performance was therefore developed:

Hypothesis 1 (H1). The density of the social networks of an R&D team positively correlates with R&D performance.

2.2. Technology ties and performance

Technology ties are connections within a network that lead to cooperation between actors, companies, and consortia, and thus create reputation effects, information benefits, and network externalities through networking processes (Lin et al., 2010). Knowledge transfer and sharing, and the location of an organizational network influence the innovative performance of that organizational network (Tsai, 2001; Chiu, 2009). Researchers have not reached an agreement as to whether a strongly or weakly tied social network configuration is most effective for attaining networked technological resources (Ahuja, 2000). The cohesion theory highlights the benefits of dense networks provided by deep accumulative experience and intensive interactions (Coleman, 1988), whereas the diversity theory emphasizes the advantages of networks with abundant structural holes that promote innovation (Burt, 2004). In addition, core competencies (i.e., those technologies that an organization excels in) are a major advantage. However, in a dynamic, changing world, core competencies may also become a millstone around a company's neck, functioning as rigidities that hinder breakthroughs (Leonard-Barton, 1992). Nevertheless, closed and dense social networks serve as distinctive capital to support technological formation and development, and further industrial growth and expansion (Obstfeld, 2005; Podolny et al., 1996; Walker et al., 1997). A dense social network links to high performance in knowledge creation and technology development (Nieves and Osori, 2013; Rhee and Ji, 2011), whereas a low-density network is a hindrance in the demand for technological coordination and quick mobilization of resources because of the lack of alignment of interests between members (Koka and Prescott, 2008). Lavie and Rosenkopf (2006) argued that links to a dense social network are opportunities for exploring technology, alliances, learning, and development. Moreover, linking players in a network with a higher degree of centrality promotes access to more technological information and resources than is achieved linking players with lower degrees of centrality (Hargadon and Sutton, 1997; Kim et al., 2006; Nieves and Osori, 2013; Stuart, 1998). The centrality of a social network often influences the locus of technological integration, resembling the new emerging centrality of technology ties (Lin et al., 2012; Stuart, 1998; Tiwana, 2008). Therefore, this research developed the following hypothesis to test whether the high centrality of social networks (those based on intimate personal relationships) contributes to the degree of technology ties.

Hypothesis 1a (H1a). The density of the social networks of an R&D team positively correlates with the associated density of technology ties.

An extensive network-based framework in which various actors collaborate to develop new ideas has replaced the solitary entrepreneur of the earlier Schumpeterian model (Laursen and Salter, 2006). The centrality of an R&D network is like the information center and is positively related to its innovative success (Tsai, 2001). Thus, to enhance the innovative performance of an R&D team, it is vital to allow members to access technological social networks, so as to enable them to increase their technological knowledge bases (Perry-Smith, 2006). Individuals with a relatively high density of technology ties tend to be seen as taking directing roles in mobilizing R&D resource allocation (Sutanto et al., 2011). Moreover, organizations with strong technology ties within the associated technological community are likely to initiate further evolution and the emergence of new ideas and innovation, and are more able to grasp technological developments and market opportunities (Rhee and Ji, 2011; Stuart, 1998; Tushman and Anderson, 1986). Therefore, the centrality of an actor's technological position reflects his or her strong technology ties and is increasingly applied to explain the power to access, mobilize, and control required or valuable resources, and therbey achieve high performance (Borgatti, 2005; Johanson and Mattsson, 1987; Stuart, 1998; Sutanto et al., 2011; Tiwana, 2008).

From this, one hypothesis can be used to test the relationship between technology ties and R&D performance:

Hypothesis 2 (H2). The density of technology ties of an R&D team positively correlates with R&D performance.

2.3. Gatekeepers and performance

Organizational communication channels must encompass the boundary spanning function to absorb external informational sources and thereby maintain continual contact with authorized outside entities to access information that the group may need (Frost and Whitley, 1971). Allen (1977) calls this role "the gatekeeper" and asserts that gatekeepers actively acquire external information sources to meet information requirements and maintain a high level of communication both inside and outside their organization. Gatekeepers are usually accomplished performers who produce more papers for presentation and publication and thus receive more recognition from their peers. They seize an important position in the evolutionary technology network, acting in the manner of problem-solving consultants and serving an indispensable role with high centrality in the network of technology ties (Shumsky and Pinker, 2003). Indeed, a significant characteristic of gatekeepers is their social networking abilities (Macdonald and Williams, 1994). Much of their expertise lies in knowing which people are reputable and proficient in specific fields, both inside and outside their firm, and in being able to quickly and effectively access, validate, and disseminate information through web-based channels (Whelan et al., 2010). Gatekeepers often play in linking different parties and advocating for innovation as well as transmitting the information crucial to innovation (Obstfeld, 2005). Consequently, externally acquired information can serve as the seed for future technological developments (Leonard-Barton, 1992). Tushman and Katz (1980) found that technological development projects with gatekeepers were significantly higher performing than those without gatekeepers. The innovation performance not only comes from internal R&D processes but also the capability to discover, identify, absorb, transform, and accumulate valuable external information; this is termed "absorptive capacity" (Cohen and Levinthal, 1990; Zahra and George, 2002). Advantageously situated gatekeepers facilitate information flow from a fixed position in a static social network. Outward orientation and novelty is a commonly cited functionality for a gatekeeper to acquire, translate, and disseminate external knowledge inwards for the organization to proactively keep pace with technological advancements (Brooks, 1985). However, in the current Internet era of open- and equal-access networks, the information searching activities of each project team member should be more important than assigning someone to be a gatekeeper (Whelan et al., 2010). Thus, this study emphasizes gatekeeper functionalities in organizations and their influence on the ability of these organizations' ability to competitively rejuvenate their core competencies, positioning, and the development of absorptive capacity, and in turn their total R&D performance. The following hypothesis, therefore, tests the relationship between gatekeeper functionality and R&D performance.

Hypothesis 3 (H3). The gatekeeper functionality of an R&D team positively correlates with R&D performance.

The acquisition of an external network of technological information by an organization is a type of technological positioning used to solve current problems, cultivate immediate absorptive capacity, thereby preventing possible technological lock-out (Stuart, 1998; Walsh, 2015). Furthermore, the gatekeeper functionalities of an organization actively accrue optimal technological advances to become a new locus of emerging technology ties, thereby influencing future development paths (Stuart, 1998; Walsh, 2015). Thus, continually acquiring new gatekeeper functionalities may enable organizational rigidity to be overcome, despite the previous success of that rigidity (Leonard-Barton, 1992). In this instance, the gatekeeper functionalities of an entity are usually closely focused on technological development, brokering knowledge fusion aggressively, and thereby earning a distinctive reputation as a technology locus with a high density of technology ties (Fernald et al., 2015). A reputable gatekeeper or an entity with active gatekeeper functionality can gain the necessary power and trust to enhance the likelihood of future technology development and collaborative ventures (Gulati and Higgins, 2003). Furukawa and Goto (2006) showed that corporate scientists with high numbers of publications are central conduits for the in-flow of knowledge from outside their companies, stimulating their coworkers to innovate through benefitting from technology spillovers.

Therefore, the following hypothesis is proposed to verify whether the gatekeeper functionality of an R&D team contributes to the development of technology ties in the scientific research community.

Hypothesis 3a (H3a). The gatekeeper functionality of an R&D team positively correlates with the associated density of technology ties.

3. Methodology

3.1. Measuring R&D performance

Because of the unpredictability of scientific research, R&D performance should be measured according to multifaceted meters rather than a single indicator (Thore, 2002). Allen et al. (1979) specified several key considerations, such as budget control, scheduling and adaptation capabilities, innovation, and cooperation beyond corporation boundaries, for measuring the technology transfer performance of an R&D task force. Katz and Allen (1985) emphasized that an R&D team achieves successful project management when scheduling, budgeting, sourcing, and innovation are performed efficiently. Reagans and Zuckerman (2001) evaluated R&D project performance using factor analysis of 11 output indicators including papers, patents, proposals, and reports. Concerning the transformation efficiency of allocated inputs, Feng et al. (2004) measured throughput efficiency by including personnel inputs, budgets, and the outputs of patents and paper publications under a data envelopment analysis (DEA). DEA simultaneously considers input and output so that scarce resources are not misallocated. DEA measures the relative efficiency of multiple decision-making units (DMUs) with a numerical coefficient that is a ratio of outputs over inputs for each decision-making unit and indicates its relative efficiency (Thore, 2002) among DMUs. The widely used DEA method conceived by Farrell (1957) and applied by Charnes et al. (1978 is based on the assumption of *constant* returns to scale. Banker et al. (1984 further developed the CCR model into the BCC model to examine *variable* returns to scale.

3.1.1. DEA for comparative efficiency

The DEA mathematical model is based on the assumption that there are $i=1,\ldots, m$ inputs; $r=1,\ldots, s$ outputs; and $j=1,\ldots, n$ DMUs. The overall efficiency value of a particular DMU (denoted by the subscript "$_0$") can be calculated using the following equation:

$$Max\theta = \sum_{r=1}^{s}\mu_r Y_{r0} / \sum_{i=1}^{m} \nu_i X_{i0}, \tag{1}$$

which is subject to

$$\sum_{r=1}^{s}\mu_r Y_{rj} / \sum_{i=1}^{m} \nu_i X_{ij} \le 1, j = 1, 2, \ldots, n$$

$$\mu_r \ge 0,\ r = 1, 2, \ldots, s$$
$$\nu_i \ge 0,\ i = 1, 2, \ldots, m$$

where $X_{i,j}$ is the ith input of the jth DMU, and $Y_{r,j}$ is the rth output of the jth DMU. The ratio of output over input, θ is less than or equal to 1 (Yuan and Huang, 2002), and a higher efficiency rating indicates that fewer inputs produce more outputs. Eq. (1) can be used to identify a set of weighted μ_r and ν_i that maximizes θ, where μ_r is the weight of the outputs, and ν_i is the weight of the inputs. When $\theta^* = 1$, the DMU is efficient. The CCR model was derived from Eq. (1) by using a linear programming transformation; the Euclidean infinitesimal number ε, which was expressed as between 10^{-5} and 10^{-6}, was introduced into the calculations (Charnes et al., 1985). Thus, the adjusted approach entails expressing the positive solution weights in the dual form:

$$Min\theta - \varepsilon(\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+), \tag{2}$$

which is subject to

$$\sum_{j=1}^{n} Y_{rj}\lambda_j - S_r^+ = Y_{r0}, r = 1, \ldots, s$$
$$\theta X_{i0} - X_{ij}\lambda_j - S_i^- = 0,\ i = 1, \ldots, m$$
$$all\, \lambda_j,\ S_i^-,\ S_r^+ \ge 0,$$

where λ_j represents the weights attached to the various DMUs, and $S_i{}^-$ and $S_r{}^+$ are input and output slack, respectively (Yuan and Huang, 2002). The value $\theta_{CCR}{}^*$ can be obtained from the optimal value in Eq. (2). Furthermore, the BCC model is derived as follows:

$$Min\theta - \varepsilon(\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+), \tag{3}$$

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which is subject to

$$\sum_{j=1}^{n} Y_{rj}\lambda_j - S_r^+ = Y_{r0}, r = 1, \ldots, s$$
$$\theta X_{i0} - X_{ij}\lambda_j - S_i^- = 0, \ i = 1, \ldots, m$$
$$\sum_{j=1}^{n} \lambda_j = 1, \text{ and all } \lambda_j, S_i^-, S_r^+ \geq 0,$$

where the $\theta_{BCC}{}^*$ derived from Eq. (3) is the technical efficiency value, indicating the real resource transformation efficiency. Thus, the CCR efficiency score represents the product of the BCC efficiency and the economies of scale of the DMU.

3.1.2. Importance of DEA for measuring R&D performance

DEA models are distinguished according to their objectives, which include maximizing outputs (output-oriented) or minimizing inputs (input-oriented), depending on the objective of the evaluation pertaining to increasing outputs (e.g., patents) or reducing inputs (e.g., parsimony budgets) (Lee and Shin, 2014). The analysis level of DMUs varies from projects (Hsu and Hsueh, 2009; Hung et al., 2013), programs (Lee et al., 2009), corporations (Hashimoto and Haneda, 2008), and institutions (Anderson et al., 2007; Feng et al., 2004) to nations (Wang and Huang, 2007). For example, DEA was used by Anderson et al. (2007) to measure the technology transfer performance of universities, by Wang and Huang (2007) to evaluate the cross-time changes of R&D efficiency under environmental moderation, by Hashimoto and Haneda (2008) to study the R&D efficiency of Japanese pharmaceutical companies, and by Lee et al. (2009) to measure national science and technology programs. National technology programs usually encompass heterogeneous objectives such as technological achievement, economic development, industrial transformation, and the establishment of a foundation for scientific education, to facilitate national planning (Lee et al., 2009; Hung and Chou, 2013). DEA is appropriate for evaluating national programs that have multiple inputs and outputs (Cho et al., 2009; Lee et al., 2009; Hung and Shiu, 2014). Relying on the relative efficiency of DEA, policy makers can evaluate the extent to which their programs have promoted the establishment of comprehensive research groups and have contributed to a successful national innovation system (Jiménez-Sáez et al., 2011).

However, most studies of R&D performance related to social network analysis have only adopted a single performance indicator such as the number of issued patents, the volume of sales, or the hazard of project completion (Gilsing et al., 2008; Lincoln and Miller, 1979; Reagans et al., 2004). Thus, the DEA approach of simultaneously coping with inputs and outputs can be used to indicate two usual mechanisms in the social network analysis: the internal network density that is able to coordinate resources efficiently and the external range spanning that can effectively search novel ideas (Reagans and Zuckerman, 2001; Reagans et al., 2004).

3.2. Dependent variable: DEA productivity scores

When evaluating the R&D performance of Taiwan's national technology programs using DEA, the input indicators emphasized the amount of money, time, and manpower invested in the program. The output indicators comprise three categories: The first relates to academic results that reflect the quality of knowledge creation, including publications and patents (Yuan and Huang, 2002). The second focuses on the quality of knowledge diffusion, measured by technological impact and citations (Wang and Huang, 2007; Lee et al., 2009). The third concerns social results, particularly education and the development of human resources, which indicate the absorptive capacity and were also targeted by the Korean National Technology Program (Lee et al., 2009). This research adopted the DEA evaluation matrices applied by Hung et al. (2013) and Hung and Shiu (2014). The amount of research subsidy represents the input capital, which is the total amount contributed to each team by the NTP from 2003 to 2007. The duration of research is the total time that an R&D team was sponsored by the NTP. The number and quality of team members was used for the input of manpower. The team members constituted the total number of R&D participants, including advisors, administrators, and assistants. The member quality was an assessment of the professional levels of the key principal investigators (PIs) and co-PIs. A score of 7 was assigned to assistant professors, a score of 8 to associate professors, and a score of 9 to professors. Similarly, the number of research papers and patents represent the output of knowledge creation, whereas paper citations and journal impacts are the output of knowledge diffusion, and the amount and quality of trained talent is used as the output of talent development. Even though the conference papers of fast-moving ICT technology readily capture attention and are published earlier than journal papers, Taiwanese scholars and research-grant-giving authorities still prefer to publishing journal papers owing to the strict scrutiny they must go through in the formal peer-review process. This research assigns equal weight to these two types of publications. The associated paper citations compiled by Google Scholar and the total impact factors of published papers indexed by the Journal Citation Reports (JCR) were collected. In addition, the total issued patents and the associated number of citations were recorded from the website of the United States Patent and Trademark Office (USPTO). The figure for trained talent refers to the numbers reported by the Taiwan Government Research Bulletin (GRB) system. The quality of trained talent was assessed by assigning part-time college students a score of 1, bachelor assistants a score of 2, part-time graduate students a score of 3, masters assistants a score of 4, part-time doctoral students a score of 5, and post-doctoral assistants a score of 6.

Finally, this research investigated 161 NTP research teams from the period 2003–2007 and applied the DEA approach to calculate both coefficients of relative efficiency—that is, the CCR (overall efficiency including the scale effect) and BCC (emphasizing the pure technological transformation efficiency) scores—by using the DEAP 2.1-XP program (CEPA, Brisbane, Australia).

3.3. Independent variables: social networks, technology ties, and gatekeeper functionality

This study measured the density of personal social networks for each NTP R&D team because the organizational density of a closed social network brings about high performance. For an academic R&D project, work and friendship relationships are the most obvious social networks, especially, the instrumental ties for work appointments of authority and education (Lincoln and Miller, 1979; Reagans et al., 2004). Team members who are involved in friendships have the opportunity to communicate outside of a work context (Kratzer et al., 2005). When R&D team members share common prior experiences, their internal network density increases, which enhances performance because of the coordination and communication efficiency that results from the strong ties (Reagans et al., 2004). Therefore, this research recorded two indicators of linkage (i.e., alumni and colleagues) from 216 PIs and co-PIs from 161 NTP research teams and thus calculated the two associated degree centralities with the UCINET v.6.3 program (Analytic Technologies, Harvard, MA, USA). There are two types of centrality computed by UCINET. One is the in-degree centrality of an actor within a social network, reflecting the level of his or her importance, which can be ascribed to his or her absorption of information or knowledge sources and role as the referral center (Tsai, 2001).

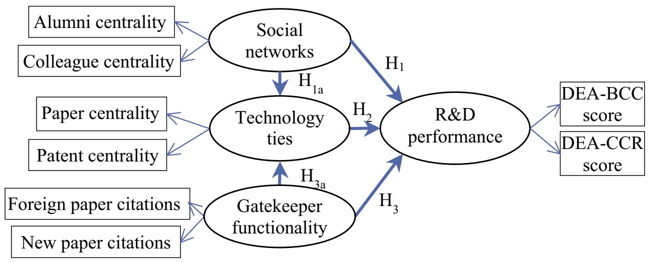

Fig. 1. Research framework.

The other is the out-degree centrality of an actor within a social network, reflecting his or her importance in disseminating information and knowledge. The combination of in-degree centrality and out-degree centrality is defined as the centrality, and a higher centrality indicates a high degree of density in the network, reflecting a higher level of importance of the actor in controlling the gateway position of the network of relationships (Freeman, 1979).

This study defined the technology ties of an R&D team by investigating the centrality of cross citations between technological patents and published papers among the scientific research community or technology network. For measuring the density of technology ties, patents and publications represent the proxy actors and their citations as the knowledge connections within an industry and thus form an expanding network of technology ties (Thompson and Fox-Kean, 2005). Therefore, this study recorded the numbers of paper citations and patent citations between 216 PIs and co-PIs from 161 teams and calculated the two associated degree centralities with the UCINET program.

To measure the gatekeeper functionality, this study targeted the paper publications of 216 PIs and co-PIs and identified two ratio types: the proportion of paper references citing foreign authors and the proportion of new references made within 5 years. The 5-year cut-off point is justified for the research target, namely Taiwan's National Telecommunication Program, which aims to advance the pioneering, broadband, and mobile technology—that is, the field of information and communication technology (ICT). According to Rodríguez (2011), a 20-year patent protection indeed appears ludicrous in ICT areas because of hypercompetition, patent thickets, and blocked standardization, with an expected effective product lifespan of less than 3 years. In addition, the waiting time to receive a patent is usually 21–32 months (USPTO, 2016). The total time to new technology disclosure is approximately 5 years. The first proxy variable reflects the gatekeepers with an outward orientation who are actively acquiring external information sources (Allen, 1977; Stuart, 1998; Walsh, 2015; Whelan et al., 2010), whereas the second indicates the gatekeepers' engagement with novel, contemporary knowledge (Brooks, 1985; Leonard-Barton, 1992). High numbers of foreign citations of an R&D team indicate more outward information searching beyond the local technology network. Increased citations of new literature indicate enhanced sensitivity to current developments. These two facets provide support to an R&D team highly involved in a dense network in escaping technological rigidity and achieving a breakthrough. Fig. 1, combining the four main constructs, shows the research framework.

This study applied partial least squares (PLS) regression for the structural equation model (SEM) because of the relatively small sample size of 161 teams (Hair et al., 2012; Haenlein and Kaplan, 2004; Thompson et al., 2007). SmartPLS v.2 software by Ringle et al. (2005) (SmartPLS, Hamburg, Germany) was used to test the measurement and convergent validity of the social networks, technology ties, and gatekeeper functionality. Additionally, SmartPLS software was used to test whether the three facets of an R&D team significantly influence its performance (Tseng and Lee, 2009).

Table 1
The profile of NTP research teams in Taiwan from 2003 to 2007.

Indicators	Mean	Standard Deviation
Inputs		
○ research subsidy (million)[a]	3.85	5.86
○ research duration (month)	24.04	12.53
○ the number of team members	4.76	6.51
○ the professional of team members	40.3	55.8
Outputs		
○ research papers	2.30	3.48
○ issued patents	10.23	12.95
○ paper citations	0.18	1.37
○ journal impacts	0.74	3.22
○ patent citations	2.47	6.12
○ the number of trained talent	9.45	16.37
○ the quality of trained talent	31.77	54.90

[a] The measurement currency is the New Taiwan dollar (NT$). The average exchange rate was about NT$33 to US$1 in the NTP execution years of 2003–2007.

Zhang et al. (1991) and Purvis et al. (2001) have argued that the bootstrapping process, which is a sampling approach using random resampling from the original sample, is efficient for enhancing construct validity for a small sample. Thus, this study used the bootstrapping method provided by the SmartPLS software and conducted resampling from the original 161 teams 500 times to increase the sample size.

4. Data analysis and results

4.1. Profile of measurements

First, the indicators corresponding to measuring R&D performance listed in Table 1 were taken. Table 1 shows the profile of 161 NTP research teams in Taiwan, including all inputs and outputs used to evaluate the DEA performance of each R&D team. The average granted R&D investment of a project team was NT $3.85 million (about US $116,700), with an average duration of two years and team size of five members, mostly led by an associate professor. The average number of patents issued was nearly five times the average number of papers published, indicating that the patent applications are more urgent in the technology industry for appropriability than the publishing of open-access journal papers. The average quality level of trained talent was a master's degree (31.77/9.45 = 3.36, which is near the notation of a master's degree in this research).

Second, the DEA efficiency scores (including BCCs and CCRs) were calculated using the DEAP 2.1-XP program. The maximum value of a BCC or CCR was one, which indicated a comparatively high efficiency, whereas a zero meant the comparatively lowest efficiency. Third, the network background of each team was investigated. Thus, the affiliation homepages of the 216 NTP PIs and co-PIs were visited, and the alumni and colleague relationships were recorded from information provided in their curricula vitae (CVs). Using the relationship matrices among the 216 NTP research participants, the centralities of alumni and colleagues were computed using UCINET. Consequently, after grouping the centralities of PIs and co-PIs into their associated research teams, the social network density of each research team emerged.

Fourth, the titles and associated authors of each published paper, as well as each patent issued by the PIs and co-PIs, were also recorded. Using Google Scholar, published papers were then checked for citation by other PIs or co-PIs of the NTP program. Similarly, the USPTO website was checked for references to the paper by other participants of the NTP program. Using the cross-citation matrices among NTP research participants, the paper and patent centralities of each PI and co-PI were calculated using UCINET. Consequently, after grouping the centralities of each participant into their associated research teams, the technology ties of each team

Table 2
Distribution of construct measurements.

Indicators	Mean	Standard Deviation
R&D performance		
○ BCC efficiency	0.49	0.31
○ CCR efficiency	0.66	0.31
Social networks		
○ The alumni centrality[a]	0.73	1.57
○ The colleague centrality[a]	1.35	1.61
Technology tie		
○ The centrality of paper citations[a]	0.07	0.20
○ The centrality of patent citations[a]	0.09	0.26
Gatekeeping functionality		
○ The proportion of foreign paper citations (%)	73.57	7.95
○ The proportion of new paper citations (%)	50.92	14.07

[a] The degree centralities of alumni, colleague, paper, and patent are calculated by the UCINET program.

emerged. Finally, according to the reference list of each paper publication in the CV, both the number of reference papers authored by foreigners and the number of references published no more than 5 years previously were counted. Thus, the average proportions of foreign paper citations and the proportion of new paper citations of each research team were calculated.

Table 2 shows the means and standard deviations of eight indicator variables of the four constructs in the research model. Both R&D performance efficiency indicators, BCC and CCR, reveal an average efficiency from 49% to 66%. There are four centrality measurements in Table 2, indicating the maximum percentage of centrality that each PI can have. The average social network centralities in terms of alumni and colleagues are 0.73% and 1.35%, respectively, and the average centralities of technology ties in terms of paper and patent citations are 0.07% and 0.09%, respectively. The gatekeeper functionality of an R&D team reveals that more than 50% of citations are novel and outward to the local technology community that the team members belong to.

Before conducting the PLS analysis, the minimum sample size for adopting PLS was examined. Eighty samples are required for the eight indicators in the path model according to the ten times rule of thumb (Hair et al., 2012). This study investigated 161 R&D teams that meet the requirement of minimum sample size. Next, the skewness and kurtosis of data underlying the eight indicators of the four constructs in Table 2 were checked. The centralities of alumni, colleagues, paper, and patent citations have high skewness values, indicating data distributions with a long tail on the right side, and large kurtosis numbers, showing a peak data distribution. These characteristics reflect nonnormality. The suitability of PLS appears, however, when facing a nonnormal distribution of the investigated data (Hair et al., 2012); thus, the PLS approach is suitable here.

4.2. Validity and reliability of measurement

Table 3 shows the reliability analysis of four constructs, including the composite reliability (CR) and the average variance extracted (AVE). According to Fornell and Larcker (1981), a latent variable with high measurement reliability should have a CR value larger than 0.6, whereas a high convergent validity requires an AVE larger than 0.5 (Fornell and Larcker, 1981). All values in Table 3 meet the criteria of measurement reliability. Furthermore, according to Chin (1998), the root of the AVE of each latent construct should be higher than that of all of the correlations among constructs in the model. As Table 4 shows, the four constructs of this research reveal mutual discrimination. Finally, Chin (1998) suggested that the factor loadings of confirmatory factor analysis (CFA) should be greater than 0.5 to indicate measurement validity when using the PLS approach. Table 5 shows that the factor loadings are large enough to meet measurement validity. Therefore, the four constructs developed by this research achieve the requirements of measurement reliability and validity.

4.3. Hypothesis testing

Hair et al. (2006) suggested that the standardized path coefficient (β) could represent the SEM model validity. Table 6 displays the hypotheses specified in Fig. 1 and the corresponding path coefficients, with the associated *t*-values. The results supported all of the hypotheses except H2. In the case of the Taiwan NTP, the density of the social network of the R&D teams positively contributes to the density of technology ties in the Taiwanese R&D community, and to the associated R&D performance. However, technology ties have no significant effect on R&D performance, whereas the gatekeeper functionality of an R&D team positively influences the performance of that R&D team, as well as its own density of technology ties.

5. Discussion

Hypothesis 1 shows that the cohesion property of a dense social network reveals the importance of implementation efficiency when pursuing targeted technology, as in the Taiwan NTP (Björk and Magnusson, 2009; Lingo and O'Mahony, 2010; Vernet, 2012). A *tertius iungens*–oriented networking strategy is necessary to coordinate the connected people to produce coordinated actions that lead to innovation (Obstfeld, 2005). Hypothesis 1a states that a social network has implications for technology transmission, with a denser social network promoting the possibility of cross-citations (Hargadon and Sutton, 1997; Nieves and Osori, 2013; Perry-Smith, 2006; Stuart, 1998; Sutanto et al., 2011). As Kilduff and Tsai (2003) showed, each actor within his or her social network not only possesses personal assets but also the flow of expertise and knowledge to mobilize knowledge creation and technology development. Hypotheses 3 and 3a suggest that the acquisition and dissemination of newly published knowledge from external sources by a research team can strengthen its technology ties for building a distinctive R&D identity within the research community (Brooks, 1985; Macdonald and Williams, 1994; Stuart, 1998; Walsh, 2015) and enhance its R&D performance (Allen, 1977; Tushman and Katz, 1980; Whelan et al., 2010; Zahra and George, 2002).

Hypothesis 2 concerns the influence of technology ties on the Taiwan NTP and does not contribute significantly to the research performance of the team, as shown in the literature (Borgatti, 2005; Laursen and Salter, 2006; Stuart, 1998; Sutanto et al., 2011; Tiwana, 2008; Tsai, 2001). One possible reason for the nonsignificant positive result may coincide with that provided by Furukawa and Goto (2006), who argued that the gatekeeper role of corporate core scientists, who published many scientific papers and possessed a high degree of knowledge reference links by others, did not apply for a considerably greater number of patents. They actually serve as the contributors not as the winners in the technological community. Another possible limitation of technology ties in this research may be that the Taiwanese research community is relatively small, especially when compared to the field of global telecommunication. Thus, Taiwanese R&D teams with strong local technology ties within the associated technological community may not be able to dominate the evolution and emergence of new ideas and innovation (Rhee and Ji, 2011; Stuart, 1998; Tushman and Anderson, 1986). Moreover, the Taiwanese telecommunication research community is still emerging and requires extensive development to catch up to the advanced level of the global telecommunications industry, as inferred from the high proportion of foreign cita-

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Table 3
Measurement reliability of constructs.

Constructs	Composite reliability (CR)	Average variance extracted (AVE)
R&D performance	0.909	0.834
Social networks	0.852	0.744
Technology ties	0.750	0.602
Gatekeeping functionality	0.748	0.597

Table 4
Correlations between constructs and the roots of AVEs.

Constructs	R&D performance	Social networks	Technology ties	Gatekeeping functionality
R&D performance	0.913[a]			
Social networks	0.341	0.863[a]		
Technology ties	0.124	0.546	0.776[a]	
Gatekeeping functionality	0.141	0.175	0.297	0.773[a]

[a] The diagonal values indicate the associated roots of AVEs of constructs.

Table 5
Measurement validity of constructs.

Variables	Constructs			
	R&D performance	Social networks	Technology ties	Gatekeeper functionality
DEA-BCC score	0.960[a]			
DEA-CCR score	0.864			
The alumni centrality		0.794		
The colleague centrality		0.926		
The centrality of paper citations			0.847	
The centrality of patent citations			0.698	
The proportion of foreign paper citations				0.752
The proportion of new paper citations				0.793

[a] The factor loadings by the CFA.

Table 6
Hypotheses testing.

Hypotheses	Path coefficients(β)	*t* values	Conclusion
Hypothesis 1: Social network → R&D performance	0.391	4.147***	Support
Hypothesis 1a: Social network → technology tie	0.500	3.617***	Support
Hypothesis 2: Technology tie → R&D performance	0.135	1.347	No support
Hypothesis 3: Gatekeeper functionality → R&D performance	0.113	1.694*	Support
Hypothesis 3a: Gatekeeper functionality → Technology tie	0.215	2.286**	Support

*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

tions shown in Table 2. Because of this, research teams in Taiwan cannot limit themselves to domestic knowledge bases. Therefore, the high degree of technology ties that resulted from increased cross-citations among Taiwanese researchers was not adequate for improving R&D performance.

6. Conclusion

The challenges addressed in this paper are especially crucial for governments, which must allocate their limited national resources carefully to enhance their R&D efficiency, emphasizing implementation efficiency over technological novelty. Some predictors of the R&D project performance have been developed on the project structure and the communication mechanism (Hung and Chou, 2013; Hung et al., 2013; Hung and Shiu, 2014; Katz and Allen, 1985; Jiménez-Sáez et al., 2011). However, this study focused on the informal R&D team's relational structure and investigated from the perspective of social networks, associated technological ties, and gatekeeper functionality, thereby verifying the predictability of each factor on R&D performance. Consequently, the empirical test from the Taiwan NTP data shows that a dense social network and the well-performed gatekeeper functionality of an R&D team enhance performance, even though dense technology ties are unable to support high R&D performance. The research results yield implications for project managers as well as the governmental policy of research sponsorship and strategic R&D partnership at the project level.

6.1. Research implications

There are three implications worthy of mention. First, in the case of Taiwan, which is an emerging market county, it is necessary for researchers to act as gatekeepers and draw from global research. This research shows that aggregative gatekeeping behavior is worthwhile. Increasing the gatekeeper function or the number of external and internal core scientists in research teams, as suggested by Furukawa and Goto (2006), Harada (2003) and Whelan et al. (2010), potentially deepens the absorptive capacity of the team and continually rejuvenates its core competence, especially from a company viewpoint. This research shows that the aggregative gatekeeper functionality of R&D teams must necessarily comprise the outward orientation, the global searching capability, and the novelty focus to keep pace with new technology. The higher the gatekeeper functionality is, the higher the R&D performance (H3) and influence (centrality) within technology ties (H3a) are. The results provide insight to governments and firms regarding subsidizing R&D projects by evaluating the gatekeeper function and job design of each applicant project. If R&D teams intend to become powerful influencers in the technological community or industry, the gatekeeper functionality is indispensable for the pursuit of technological advances. For academic researchers, the perspective of gatekeeper functionality should be extended to include Internet penetration capability to discover efficient information searching behaviors of gatekeepers beyond the publication citations observed in this research.

Second, social networks have a positive impact on research performance, with contributions resulting from multiple personal network resources. As the research of Hung et al. (2013) demonstrated, 48% of research teams in Taiwan are located in four key national universities, at which the primary resources are gathered and from which important achievements originate. This research suggests that efficient project management and R&D economies of scale at the government or firm level emanate from research teams with a higher network density. Koka and Prescott (2008) stated that a dense network increases the probability of developing strong ties and thus facilitates the transfer of tacit knowledge, thereby having a positive impact on innovative performance. Rost (2011) argued that extracting innovation from cooperation requires opportunity brokerage and the coordination and mobilization of resources by strong ties in the network. A dense social network fulfills this role. As with previous research, this study shows that personal friendship networks support technology linkage (H1a) as well as the final R&D performance (H1).

Thirdly, as the non-significance of Hypothesis 2 shows, teams locating with high centrality of technology ties may not produce significant R&D results. Hence, the grant–providing research authority should further examine their sponsorship policy. They should question, in particular, the value of past investments in reputable and distinguished professors and their associated laboratories, which accumulated high centrality of technology ties among Taiwanese academic research society. However, as Furukawa and Goto (2006) noted, the core scientists deserve very dense technology ties because they serve as gatekeepers who facilitate knowledge diffusion and sharing and stimulate more innovation. Even though they may be less productive in patent application, their real contribution should not be measured beyond a mere cost-benefit analysis. Moreover, such teams with high centralities of technology ties may not only produce distinctive, explorative technologies, but also consume a high volume of resources for those technological breakthroughs, with an inefficient DEA ratio of resource conversion consequently. Therefore, at the firm or governmental level, such latent mediating research teams should be evaluated cautiously.

6.2. Research contributions

Because the measurement of social networks is challenging (Reagans et al., 2004), this research developed a new measurement approach for networking analysis. Two corresponding networks were used to measure the centralities of the social network and technology ties respectively. Most researchers have constructed the network structure of a targeted organization by asking correspondents (actors) to recollect the relationship between themselves by using their implicit impressions rather than explicit linkages (Obstfeld, 2005; Reagans et al., 2004). The method of this paper differs by directly using bibliographical data regarding education, affiliations, and achievements, to reduce the referral bias and investigation costs (Thompson and Fox-Kean, 2005). This research directly adopted data about respondents' alumni, colleagues, and publications without the use of interviews.

In addition to social and technological networks, this research also measured the importance of gatekeepers by examining teams' total gatekeeping behavior rather than identifying gatekeepers through direct communication with team members as in Allen (1977). The direct detection of publication citations can be used to reflect outward orientation and examine the extent of the time-delayed gap in keeping pace with technological advancement. The validity of proxy variables can be verified by more research for generalization. If bibliographical data is used to directly examine the social and technological networking pattern, proxy variables proposed here can be applied to reduce the bias of a respondent's self-refection. Moreover, the governmental or firm authorities giving R&D grants can undertake detailed scrutiny of the networking pattern among the project applicants to promote a better R&D collaboration for higher performance.

This research applied the widely used DEA approach to indicate the efficiency of resource transformation, and linked it to the networking power of R&D organizations. Previous research has only adopted a single indicator to reflect R&D performance, including explorative and exploitative innovation outputs (Obstfeld, 2005; Reagans et al., 2004; Tiwana, 2008). There are two key streams of social network analysis, with the cohesion stream emphasizing the exploitative efficiency of coordination between input resources (Coleman, 1988), and Burt's structural holes theory (2004) stressing catalysis for exploring novel outputs. DEA can be used to integrate these two streams because it is concerned with the ratio of outputs over inputs. A large numerator illustrates Burt's emphasis, whereas a small denominator exemplifies Coleman's cohesion efficiency. For countries like Taiwan, with limited resources, the efficiency of allocating limited R&D resources is important and deserves more research to determine better R&D organizational structure under the framework of performance evaluation.

6.3. Research limitations

This paper examined the integrated evaluation of NTP research teams. However, information on the outcome and impact of a research program is typically delayed for several years and the R&D inventory requires continual updating to enable an objective evaluation of R&D performance. For example, the paper citations on Google Scholar, and the issued patents and associated citations in the USTPO, are constantly changing. This paper confines the NTP performance data to that accumulated before 2009, the year after the NTP program ended. Updated data may be used to verify the arguments made in this paper in the future. However, the actual value of ICT-published papers and patents usually decreases dramatically after 3 years (Rodríguez, 2011), and thus, the reliability and validity of the current data may still justify the analysis. However, further studies of different national technology program data or updated Taiwan NTP data could be used to examine the generalizability of the arguments of this research.

This research may reflect an incongruity problem between the measurement and the analysis units. The technology ties of the targeted technology indeed exceed the local investigated scope. Thus, the nonsignificant result of H2 indicates a future research direction, namely covering the global technology network and examining important technology flows involved in drawing the technology ties. Technology development usually demands international standards and cooperation (on telecommunications in this research case), and Taiwan's research society, although a quick follower, is only a small part of the global technology network.

Moreover, this study targeted academic research teams that are focused on the precompetitive stage of an innovation and are more idealistically concerned with the publication of scientific knowledge. Conversely, most national technology programs include an empirical sector, which emphasizes the speed of tech-

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nology development, the time to market, and the improvement and transformation of the national industry. Therefore, industrial participants, including corporations and independent R&D institutions, should be involved. The networking pattern between for-profit entities is more demanding than in the academic community. However, additional empirical studies should be conducted in the future to further understand the influential relationships among social networks, technology ties, gatekeeper functionality, and R&D performance.

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