Dynamics of a technological innovator network and its impact on technological performance

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ABSTRACT

This paper examines the dynamics of a technological innovator network (TIN) of a state-owned textile company in underdeveloped southwest China. It addresses two research questions: how the structure of the TIN evolved in the past 10 years; and what impact it had on the technological performance of the firm. The case study reveals that the general structure of the TIN and the positioning of the actors influence not only the amount of technological innovations but also the predominant type (product versus process innovations). TINs that are adequate for process innovation may not be as efficient for product innovation.

Keywords: Technological innovator network; technological innovation performance; product and process innovation; network structure; network dynamics; China

1. INTRODUCTION

It is now generally accepted that innovation is the result of an interactive process. Innovation is not an isolated process of individuals or firms but is the outcome of the interaction of firms, customers, suppliers, competitors and various other private and public organisations in a system (Lundvall, 1988, 1992). Through a complex web of interactions, individuals and organisations exchange the knowledge needed for the development of new products or processes or the improvement of existing ones. Understanding the drivers of innovation requires an in-depth analysis of the social relationships and organisational structures supporting the exchange of knowledge and information across the different actors in an innovation system (Lundvall, 2004).

Consequently innovation studies scholars have largely analyzed the role of networks in the generation of ideas and their transformation into new products or processes (Powel and Grodal, 2005). Broadly speaking, an innovator network can be defined as a web of individuals or organisations whose interaction supports the emergence and development of innovations. While some authors have been mainly concerned with the geographical location of innovator networks or its stickiness (Beccatini, 1990; Camagni, 1991; Cooke, 1996, 1998; Marshall, 1930; Piori and Sabel, 1984; Storper, 1997; Asheim and Gertler, 2005), others have largely studied how the intrinsic characteristics of the network in terms of structure (Das and Teng, 2002), governance (Pietrobelli and Rabel-

lotti, 2009; Gereffi, 2005; Sturgeon and Van Biesebroeck, 2008), cognitive distance between the participants of the network (Gilsing et al., 2008) or the strength of the ties (Granovetter, 1973) affect the transfer of knowledge and consequently the emergence or development of innovations (Nooteboom, 2004). While these studies have been extremely helpful in understanding how networks might support the emergence and development of innovation, they still are rather limited.

Most scholars have focused on the role of inter-organisational networks in shaping innovation (DeBresson and Arnesse, 2001; Freeman, 1991; Hagerdoorn, 1990, 1993; Nooteboom, 2004; Powell et al, 1996; Soh and Roberts, 2003) and innovation systems (Giuliani and Bell, 2005; Kastelle et al., 2009). There are not yet many empirical studies on the role of intra-firm networks on innovation and organisational learning (Dantas, 2006; Jensen et al., 2007) and even fewer on the interplay between intra- and extra-organisational networks shaping innovation.

Furthermore, most of the studies conducted hitherto are based on qualitative methods of analysis. When quantitative analysis has been performed, authors have mainly focused on formal networks as the independent variable and patents as the dependent variable, thus neglecting other forms of networks as well as other measures of innovative output like new products, services, organisations, etc. (Powell and Grodal, 2005). Hitherto most of the studies on intra-firm networks are at the individual level in which individuals are taken as nodes of the network. Networks of groups and organisations are not very common. The reason is that some researchers doubt if it is possible or applicable to use social network analysis (SNA) for other type of nodes other than individuals.

The lack of empirical studies is particularly dramatic when it comes to traditional industries[1]. Those that exist often examine high-tech industries where technological collaboration is paramount for the success of innovation projects.

This paper attempts to analyze the dynamics of a technological innovator network (TIN) of a state-owned company named Grace Corporation for the past 10 years. Grace is an innovative company in a traditional industry (textiles) located in relatively underdeveloped southwest China. The paper opens the black box of the company by taking the different functional departments as research units. It breaks the organisational boundary by having the outside organisations involved in the network. We explore how the structure of the intra-firm and extra-firm TIN evolved in the 10 years of technological innovation and how it impacted on both process and product innovation. To do so, we use social network analysis to map and measure the relationships between different departments and organisations inside and outside the company. The social context and economic environment of relatively underdeveloped southwest China are considered as important background and influencing factors that have shaped the pattern of technological innovation in this case. Case study is used as our main research method, as we believe that this can help us to obtain a clear picture of the dynamics of TIN inside a firm and deeper insights into how TIN impacts technological innovation.

The remainder of the article is structured as follows. In the next section we review the literature on innovator networks and technological innovation, paying particular attention to the links between the two. In sections three and four we describe the research methodology and the analytical framework that we use in our analysis. The company that we analyse in our study (Grace Corporation) is presented in section five and the results of the analysis are depicted in section six. Finally, we discuss the theoretical and empirical implications of our analysis in a concluding section.

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[1]   Taking the ABI/INFORM database as an example, we found 1528 papers using the key words of innovation, network, and high-tech, but only 13 papers using innovation, low-tech or medium-tech or traditional industry. It is also deficient in research on developing countries, in particular the underdeveloped areas of these countries.

2. THEORETICAL BACKGROUND

2.1. Technological innovation as a networking process

Among innovation scholars, it is generally accepted that firms and other organisations do not innovate in isolation but in continuous interaction with other organisations, forming a system of innovation. Innovator networks shape the structure and dynamics of a system of innovation and thus its performance and vice-versa; the institutional frameworks and the socio-economic structure in which the actors are embedded also determine the form and functioning of the networks.

Technological innovator networks are complex structures embracing horizontal and vertical linkages and all activities supporting the emergence and development of new products or processes. Among these supporting activities, one can include financial services, technology suppliers and more general knowledge suppliers, etc. In the social network analysis literature (Scott, 2002) networks are defined as a set of nodes connected by a set of ties. Nodes are the actors or players of the network, and are considered as interdependent rather than independent autonomous units.

One could argue that there are two main lines of research concerned with innovator networks. Those focusing on the ecology of the network, that is, how external factors such as formal and informal institutions or the embeddedness of the innovator network in a specific location influence the dynamics of the network; and those analysing the internal characteristics of the network in terms of composition or structure, governance, properties of the ties, capabilities of the actors involved in the network, etc.

According to the first line of research, clearly dominated by economic geographers, proximity with other members of the network facilitates the exchange of codified but, more importantly, non-codified or tacit knowledge (Beccatini, 1990; Camagni, 1991; Cooke, 1996; 1998, Marshall, 1930; Piori and Sabel, 1984; Storper, 1997; Asheim and Gertler, 2005). Tacit knowledge is more difficult to transfer than codified knowledge. Accessing tacit knowledge often requires a close interaction with the source of that knowledge. This sticky character of knowledge explains the strong geographical embeddedness of certain networks forming clusters and the success of certain regions such as Silicon Valley (Saxenian, 1994) or the so-called Third Italy (Beccatini, 1990). The degree of trust among the participants in the network as well as a shared culture facilitate the exchange of knowledge and point to the importance of institutions in the dynamics of the networks (Lundvall, 2007; Johnson, 1992), while the existence of different cultural backgrounds might hinder the transfer of knowledge among the participants in the network (D'Costa, 2003).

Following the second line of research, three elements are usually taken into account when analysing the intrinsic characteristics of the networks: the general structure of the network, the positioning of the individual actors in the network, and the strength of ties between the actors. What are they and what might be the expected impact on technological innovation are discussed next.

Structure of the network

The size and composition of the network, the density of the network and its centrality are important aspects to consider when discussing the potential impact of networks on technological innovation.

Although most authors equal networks to inter-organisational networks, it is possible to distinguish between inter-firm networks (DeBresson and Amesse, 1991), inter-organisational networks (Freeman, 1991) and even intra-firm networks supporting innovation (Tsai, 2001; Lam, 2005; Nonaka and Takeuchi, 1995). In inter-firm networks all nodes are firms and all ties are between firms. Studies on user-producer networks (Lundvall, 1992), inter-industrial networks and clusters (Malmberg and Power 2005; Porter, 1998) are usually inter-firm networks. Inter-organisational networks involve other types of organisations, such as universities, research centres, financial

institutions or the government. The innovation systems literature (Lundvall, 1992; Asheim and Gertler, 2005; Malerba, 2005) as well as the most recent cluster literature (Porter, 1998) implicitly use this definition of a network. Finally the concept of intra-firm network has been mostly used in organisational studies to refer to the linkages established between different departments of the firm (Lam, 2005). With very few exceptions (Lundvall, 2007), these two approaches (inter vs. intra firm networks) have mostly evolved in parallel and with very few interactions[2].

The density of the network is usually measured in terms of the number of direct ties between the participants of the network (Scott, 2000) and has important implications for the access to competences and the governance of the networks and thus on innovation. Sabatier and Jenkins-Smith (1993) argued that dense structures tend to reinforce inertia and can be hostile to innovation, while McCarthy (2008) reached the opposite conclusion that a dense network helped spread institutional norms of behaviour and also facilitated the transfer of information which is important to innovation. The latter studied the process of network evolution and transformation in health insurance in Ireland and found that the network was characterized by high centrality, high density and weak ties, and cost efficiency was a key outcome. The positive relation between density of network and learning is also justified by the research by Tsai (2006) on the impact of website structure on customer knowledge flow and innovation in internet marketing in Taiwan and the extensive literature on clusters (Saxenian, 1994; Piore and Sabel, 1984). Carlsson and Sandström (2008) conducted a comparative case study of four networks within the higher education policy sector and proposed that an efficient and innovative policy network consists of a heterogeneous set of actors that are centrally and densely integrated.

The degree of centrality measures the extent to which a network is centralized. It has important implications for learning and innovation as it influences, for example, to what extent other actors can participate in the network, the bargaining power of the different actors or the control of information (Nooteboom, 2004). Pietrobelli and Rabellotti (2009) show that very centralized forms of networks with hierarchical or captive patterns of interaction tend to hinder the transfer of knowledge and thus interactive learning, and innovation is less likely to occur. In more decentralized networks where there is no clear dominant actor that controls important direct ties, other actors can access information more fluidly. An increase in the degree of centrality might imply a risk if the central actor restricts the access of information for other actors, but it might also facilitate the coordination of different actors, which might be required in complex innovation processes. About the relation between network centrality and innovation, Herminia (1993) argued that network centrality is the strongest determinant of individual involvement in innovation efforts for administrative innovation, but not for technological innovation. Ebadi and Utterback (2000) studied 117 Sea Grant research projects and found that on the one hand, on an individual level frequency of communication affected technological innovation and so does centrality and diversity; on the other hand, on the organisational level, network cohesiveness, centrality, and diversity of communications were all positively related to technological innovation. In sum, as with most of the variables discussed in this section, the impact of centrality on innovation is not clear.

Positioning of individual actors

All sociologists would agree that power is a fundamental property of social structures and is inherently relational. Hanneman and Riddle

2   Lundvall (2007) argued that the impact of innovation on economic performance will typically depend upon changes in 'people', 'orgware' which refers to how people relate to each other within organisational borders, and 'socware' which refers to how people relate to each other across organisational borders. The 'orgware' and 'socware' are interpreted as the structural attributes of intra-firm networks and inter-organisational network in this paper.

(2005) argued that power in social networks may be viewed either as a macro property which describes the entire population, or as a micro property which describes relations between actors. Burt (1992), Wasserman and Faust (1995) also defined two approaches to network analysis, with one approach focusing on the whole of the network itself and another on characteristics of particular actors in a network. As with other key sociological concepts, the macro and micro are closely connected in social network thinking.

We may expect that the positioning of individual actors and how they are connected to other actors of the network also have important implications for technological innovation. A central or bridging positioning in the network, or a close link to an actor that has multiple connections, ensures access to critical resources (Scott, 2000; Nooteboom, 2004). On the contrary, a peripheral position in the network and the need to go through many nodes to access the relevant information might severely hamper the flow of knowledge and thus innovation within the network.

Strength of ties

The positioning of individual actors is also related to the strength of the ties that the actor has with the other actors within the network. There is a large amount of literature on the advantages of weak (not intense) vs strong (intense) ties in networks (Granovetter, 1973). But (again) it is not conclusive when it comes to the impact of the intensity of the networks on innovation. On the positive side, weak tie networks may provide access to novel and non-redundant information and introduce flexibility in the network, while strong ties may facilitate the exchange of complex information. On the negative side, strong ties may end up in lock-in situations and lack of renewal of ideas and knowledge (D'Costa, 2002; Narula, 2002).

2.2. Technological innovation including product and process innovation

Technological innovation in this paper refers to *product innovation,* which consists of new or better material goods as well as new intangible services, and *process innovation,* which comprises new ways of producing goods and services (Edquist, 2005). Innovation is generally considered to be the development and introduction of new products or new processes or new forms of organisation in the firm. As argued by Fagerberg (2005) – despite the fact that one of the founders of innovation studies (Schumpeter) considered at least five different types of innovation: new products, new methods of production, new supply sources, access to new markets and new forms of organisation – innovation scholars in general and economists in particular have mainly focused on just the two first ones: product and process innovation. This is also the approach followed in this paper.

One of the most used definitions of innovations is found in the Oslo Manual (OECD, 2002). The Oslo Manual distinguishes between technological and non-technological innovations and between products and processes. Technological innovations 'comprise implemented technologically new products and processes and significant technological improvements in products and processes' (OECD, 2002: 31).

Product innovations comprise both goods and services and they refer to technologically *new* products and technologically *improved* products. Technologically new products are products 'whose technological characteristics or intended uses differ significantly from those of previously produced products. Such innovations can involve radically new technologies, can be based on combining existing technologies in new uses, or can be derived from the use of new knowledge' (OECD, 2002: 32). On the other hand, technologically improved products are products 'whose performance has been significantly enhanced or upgraded. A simple product may be improved (in terms of better performance or lower cost) through use of higher-performance components or materials, or a complex product which consists of a number of integrated technical sub-systems may be improved by partial changes to one of the sub-systems' (OECD, 2002: 32).

Process innovation, as defined by the Oslo Manual, is 'the adoption of technologically new or significantly improved production methods, including methods of product delivery. These methods may involve changes in equipment, or production organisation, or a combination of these changes, and may be derived from the use of new knowledge. The methods may be intended to produce or deliver technologically new or improved products, which cannot be produced or delivered using conventional production methods, or essentially to increase the production or delivery efficiency of existing products' (OECD, 2002: 32).

3. RESEARCH METHODOLOGY

When studying the complicated dynamics of a technological innovator network (TIN) there is no single method which is competent. Therefore, phenomenological methodology and case study method and social network analysis are used in this paper.

3.1 Case study

The case study method is used to understand the major issues surrounding the technological innovation in Grace. Different sources of evidence are utilized, including questionnaires, interviews, direct observations, archives and statistics. In the data collection phase, we used one semi-structured questionnaire to collect the relational data of the TIN of Grace. Overall, six visits were made and 25 interviews conducted during the period of December 2004 to January 2008. The interviewees included the president and chairman of the board, the vice-general manager, the directors of the middle-level management team from 7 different sections: the Science and Technology Administration Department, the Domestic Marketing Department, the International Marketing Department, the Strategic Planning Department, the intellectual property right (IPR) Office, the HR Department, and the Real Estate Company and individual engi-

neers and workers. Typically each interview lasted for about 1–2 h. The interview phase took about 8 non-consecutive weeks[3]. An agreement was reached with Grace over business secrecy. Informal discussions with the members of the organisation provided us with a better understanding of the important themes underlying the firm's practice of organisational learning and technological innovation. In the data clarification and complementation phase, we contacted Grace's managers via email correspondence and telephone discussions for further information and data, and to clarify unclear points from the previous interviews.

There is always a certain degree of bias when recalling information about past networks. In order to control for that potential bias of the respondents we triangulated the information provided in the questionnaire and interview with archives, such as yearly memorabilia of the company on S&T activities in which important co-operations were filed. This was as a consequence of the company's very aggressive compensation policy on innovation. They not only rewarded good results but also good activities of technological innovation. So they carefully filed those activities. Additionally, 25 employees on all management levels were interviewed. Their answers about the networking activities can complement and corroborate each other. Most of the employees and managers we interviewed in Grace have worked for the company since it began 1980s and have witnessed the change of the company. Finally, it should be noted that all the interviewees were asked to support with facts all the relationships that they mentioned. That is, when they indicated that the company had cooperated with a partner, they were asked to provide information on what kind of cooperation it had with that specific co-operator.

3.2 Social network analysis

Social network analysis (SNA) has been adopted as the analytical tool in this research. The social

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[3] All the interviews were well recorded on paper but not recorded on tape since the informants were reluctant to have their views tape recorded.

network perspective encompasses theories, models, and applications that are expressed in terms of relational concepts or processes (Wasserman & Faust, 1994). Social network analysis focuses on uncovering the patterning of people's interaction. It is based on an assumption of the importance of relationships among interacting units and on the intuitive notion that these patterns are important features of the lives of the individuals who display them.

NetDraw and Ucinet software programs were used to map the TIN of Grace and detect the properties of the network in order to understand the pattern and dynamics of it.

4. ANALYTICAL FRAMEWORK

4.1 Definition of the technological innovation network

This paper defines a technological innovator network (TIN) as a combination of intra-firm and inter-organisational networks.

In the intra-firm network of this paper, instead of commonly taking individual as the node, we identify the nodes as groups of people who serve in different functional departments such as marketing, financial, R&D, and human resources (HR) within the firm. Some researchers question whether there is a need to talk about networks of groups which made up of individuals already involved in social networks. We argue that SNA on networks of groups and organisations is both applicable and necessary. On the one hand, SNA is based on an assumption of the importance of relationships among interacting units or nodes. If relations between individuals are defined by linkages among them (Scott, 2000), it is also applicable to define the relations between groups, or more generally, organisations in the same way. However, SNA on network of groups/organisations is different from and non-substitutable by SNA on networks of individuals. Organisational behaviour can be analyzed on three different levels, namely individual, group, and organisation (Robins, 2002). A group is a combination of individuals but the behaviour of a group is not a simple addition of the behaviour of individuals thanks to the synergy and antagonism between individuals. Therefore, distinguishing networks of individuals from networks of groups/organisations is necessary. Furthermore SNA on networks of individuals, which is at the very micro level, is more suitable for HR workers rather than for general strategy makers who need information of middle-scale level.

In the inter-organisational network of this research, the nodes are formal structures that are consciously created and have an explicit purpose (Edquist and Johnson 1997). They are organisational actors such as educational and scientific research institutes, non-governmental investment institutions, customers, suppliers competitors, and so on.

The focus on the interplay between intra- and extra-firm networks makes the picture of firm's technological innovator networks complete and clearer than just focusing on either of these two networks. We can therefore deeply understand how a firm's functional strategy, which concerns the managerial game plan for running a major functional activity or process such as R&D, production, etc. within the firm, copes with the firm's business strategy, which concerns the actions and the approaches crafted by management, such as building up collaborative partnerships and strategic alliances to produce successful performance in the firm's business.

For the analysis we consider both formal and informal ties. Network dynamics in this paper refers to the evolving or changing structure of the network, such as breaking or making of ties. We attempt to take snapshots of the TIN during its evolutionary process in the past 10 years[4].

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[4]   In doing so, we consciously ignore the dynamics on the network due to the change of the actors themselves.

4.2 Parameters to analyse the technological innovation network

Following the discussion in the previous section, we use two main groups of parameters in this paper: the first is network properties to describe the TIN structure as a whole, and the second is node properties to identify and understand the position which reflects the opportunities and constraints of a specific actor in the network. The network properties referring to the structure of the network include composition of the network, density, centralisation, efficiency, and diversity. The node properties regarding the positioning of actors in the network comprise node centrality, including Freeman's (1979) degree and Bonacich's (1972) power, closeness, and betweenness. These measures have come to dominate empirical usage to identify the most important actors within the network (Borgatti, 2005). Each measure has various relative advantages and disadvantages concerning its use. We define these measures as follows.

Structure of the network

Composition of the network: We identify eight internal actors, which are different functional departments and groups inside the company, and 10 external actors, which are different organisations outside the company (see Table 1). To examine the connections between inside actors we ask the question: 'Do the different functional departments and groups contact each other when doing technological innovation activities?'.

Density: this is a measure of the connectedness between nodes in a network (Scott, 2000). It is expressed as a proportion of the actual number of ties to the maximum possible number of ties in a network. Scott (2000) pointed out that density is the most widely used and the most possibly abused concept as it is sensitive to the size of the network. It cannot be used for comparisons across networks that vary significantly in size. Since what we analyze is the same network with no significant change in size, the density of the TIN of Grace in different periods of time is comparable.

Centralisation: network centralisation expresses the degree of inequality or variance in the network as a percentage of that of a perfect star network of the same size. It measures to what extent the network as a whole is centralized.

Efficiency: we measure efficiency of the network as the extent of difficulty for a node to get access instantly to a large number of nodes through a relatively small number of ties. Its proxy is the average distance of the network.

Positioning of actors

Degree centrality: reflects how a node is connected in the local environment is expressed by the number of direct ties with other nodes. High degree means more ties which provide the actor with alternative ways to satisfy needs, and more chances to be the third-parties and deal makers in exchanges among others. Consequently, actors with a high degree of centrality are in an advan-

TABLE 1: ABBREVIATION OF ACTORS

Inside actors		Outside actors	
PRD	Production department	UNI	Universities
FIN	Financial department	RI	Research institutes
HR	Human resource department	SPL	Suppliers
RD	R&D department	CST	Customers
ST	Science & technology administration department	CPT	Competitors
		GOV	Government
MKT	Marketing department	INV	Private investors
PCH	Purchasing department	LAW	Legal services agencies
LOG	Logistic department	CSL	Consulting companies
		IA	Industrial associations

taged position. To measure the degree centrality of the network actors, we use both Freeman's degree and Bonacich's power. Freeman's degree measures the degree of variance in a network as a percentage of that of a perfect star network of the same size. Bonacich's power can be considered as an advanced version of Freeman's as it captures not only the direct ties to other nodes but also the ties that those other nodes have (Hanneman and Riddle, 2005).

Closeness: reflects to what extent a node is the centre of the network is expressed by the sum of the distances from a particular node to the other nodes in the network. It emphasizes the distance of an actor to all others in the network by focusing on the distance from each actor to all others.

Betweenness: reflects to what extent a node is standing between the others. Together with closeness, betweenness measures an actor's capacity to control communication in a network, which depends on its relations to all members of a network and not necessarily on the number of links to immediate neighbours.

Strength of ties

To measure the strength of the connections to the company's technological innovation, we asked the respondents to score the importance of a connection which is represented by the 5-level Likert item. We also conducted the same examination and measurement regarding the connections between the inside actors and outside actors, as well as the connections among the outside actors. The responses allow us to conduct the core–periphery analysis presented in the next section.

4.3 Technological innovation performance

In this study, technological innovation includes product innovation and process innovation. The sales of new products as a percentage of the total sales are used to measure the product innovation performance. The number of successful process innovation projects is used to measure the process innovation performance.

The new products refer to the products developed and produced by new technological elements and new design, or those with obvious improvement in structure, material, and process compared to the existing ones, or in general those with obvious improved performance or expanded functions. Considering the nature of chemical fibre products, we set a period of three years of expiry for the new products from the year they are first introduced into the market.

The successful process innovation projects refer to those whose outcomes have been put into practice in the year.

In order to compare these two different categories of performance and to obtain a comprehensive measurement of technological innovation performance as a whole, we use an efficacy coefficient method to turn the two indicators into comparable indexes. The model of these indexes is as follows:

$$d_j(x) = (f_j(x) - f_{jmin})/(f_{jmax} - f_{jmin}) \times 40 + 60 \in [60,100], \quad j = 1, 2, \ldots, p$$

$$D = \left(\prod_{j=1}^{p} d_j(x) \right)^{1/p}$$

$d_j(x)$ - single index, i.e. index of product/process innovation performance

D - multi objective, i.e. index of technological innovation performance

5. Case description

This paper is based on observations of technological innovation activities in a state-owned textile company named Grace Corporation which is located in Yibin city of Sichuan province in Southwest China. It grew out of a small state-owned chemical fibre factory founded in 1984. Until 1997 it was a small factory on the edge of bankruptcy. 1997 was a milestone in the history of Grace marked by the change of top management and the invention of a revolutionary technology called '2S' which can double

production at very low cost.[5] Since then Grace has experienced a high growth rate, that is, increase at an average annual rate of 35%. Now it is one of the world's largest manufacturers of viscose filament yarn, rayon embroidery thread and hand knitted garments with total assets of 3.9 billion RMB and 12,000 employees. The world market share of its products reached 29 per cent in 2007.[6]

There are many outstanding occurrences related to technological innovation in this company, which deviate from the common trend in China.

First, in this company the annual R&D investment as a percentage of sales has increased from 3% to 9% in the past 7 years, a figure far higher than the average level of 0.2–0.5% in China's textile companies.

Second, this company benefits significantly and continuously from a technological innovation – '2S'. This technological innovation has strongly supported the high growth of this company at an average annual rate of 35% in the past 10 years.

Third, they have 114 patents compared with an average of below 8 patents for the import and export enterprises in Sichuan province. [7]

Fourth, there is a strong corporate culture supporting innovation. Innovation has the most priority in Grace. Grace managers are required to pay more attention to innovation than to daily production, and innovation performance is the most important criterion for compensation. When it comes to encouraging technological innovation, the most famous notion of the Grace President is 'rather incorrectly reward 1,000 people who do not deserve than omit one person who deserves'. The innovative culture of Grace has encouraged people to do their best to innovate in the company and has successfully created an internal environment for innovation when the external environment is still conservative.

Fifth, in this company it is difficult to find one single successful joint research program with social knowledge infrastructures such as universities and scientific research institutes in the past 10 years. The overwhelming majority of technological innovations are from within the company. It appears that introverted innovator network has successfully supported the prosperous technological innovation activities in Grace. The question, as we will discuss later, is if this is sustainable in the long term.

6. CASE ANALYSIS

We analyze the dynamics of the TIN of Grace in the past 10 years in relation to its technological innovation. The analysis is conducted as follows. First, we divide the history of Grace's technological innovation into three different stages. Second, we take a snapshot of each of these stages using a socialgram to give an intuitive image of the TIN of Grace. Third, we detect the properties and analyze the dynamics of the TIN of Grace over these three stages to see how the evolution of the TIN's structure influences the firm's technological innovation.
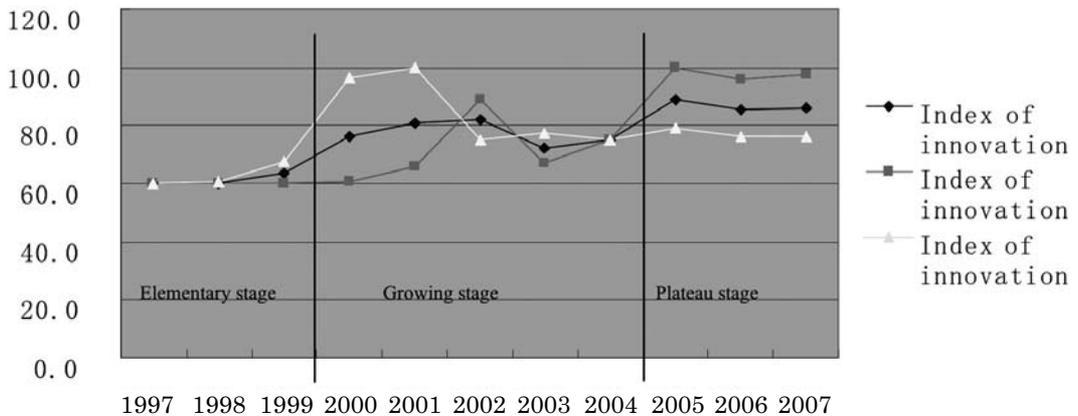
6.1 Three stages of Grace's technological innovation history

We divide Grace's technological innovation history taking into account the performance of its technological innovation, including the performance of product innovation and process innovation and the discussions maintained with the Grace managers and president. According to them, the history of Grace's technological innovation can be divided into three stages: 1997–1999, 2000–2004, and 2005–2007.

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5   2S is a process innovation which doubles the production output at very low cost. It breaks with the conventional principle of spinner designing which has existed for over 100 years. The typical methods to raise output of spinning machines are to lengthen the spinner or to speed up spinning. These two approaches are either costly or restricted by the technical limits of the spinner. But 2S does it differently. Traditionally the spinner produces one filament with one spindle. With the 2S technology, the spinner can produce two filaments with one spindle at the same time. 2S is a radical innovation, which is described as an A-bomb in the textile industry.

6   Source: Publicity Department, Yibin Grace Group Co., Ltd.

7   Source: Report of the Soft Science Project of State Intellectual Property Office of People's Republic China 'Investigation and case study of the situation of intellectual property rights in Sichuan Import & Export Enterprises'.

GRAPH 1: TECHNOLOGICAL INNOVATION PERFORMANCE OF GRACE FROM 1997–2007

The first stage running from 1997–1999 is considered as the 'elementary stage of technological innovation'. It is characterized by three historical events. The first is the change of top management. The current Chairman and President, Feng Tao, was assigned by the local government. The second is the invention of the historically important technology '2S', which is a process innovation which makes it possible to double production at a very low cost. The third is the massive recruitment of 600 new employees. Most of the current mid-level managers are from this group of people. This stage is a turning point, changing an old factory on the verge of bankruptcy to an innovative enterprise. But the innovation performance was not high or significant at this stage.

The second stage from 2000–2004 is labelled as the 'growing stage of technological innovation'. It is also called by Grace the 'first spring of technological innovation'. The main characteristics of this stage are the invention of a large number of influential and profitable technologies, and the rapid growth fuelled by the prosperous technological innovation. There are two symbolic events: a boom of patenting including the key technology '2S', the establishment of a Science and Technology Administration Department and IPR Office (both of them report directly to the president), and the launching and implementation of a policy which significantly rewards the actors and activities of technological innovation. We observe a drop in the percentage of new product sale to total sale during this period. However, this was not because of a slowdown in technological innovation but because of a market reason. From 2003–2004, 2S technology was illegally imitated by all the main competitors of Grace and its sale of the new product was significantly influenced by this infringement.

The third stage from 2005–2007 is considered by Grace managers as the 'plateau stage of technological innovation' of Grace. In this stage, the performance of product and process innovation further increased in 2005 but then dropped slightly and more or less stagnated at a stable level in the next two years. According to the interviews, this period is characterised by technological-innovation fatigue of the employees and a lack of technological talents as a result of their movement from technological positions to managerial positions. To boost its technological innovation, Grace initiated the creating-the-second-spring-of-technological-innovation campaign by the end of 2005. But the campaign was not very successful.

The analysis of some indicators of technological performance during this period provides additional information on what has happened in terms of technological innovation in Grace over this 10 period year. As Graph 1 and Table 2 show, until 2001 Grace excelled in process innovation. The period between 2002 and 2003 was an inflexion period. From 2004 onwards, the technological performance of product innovation exceeds that of process

innovation. This finding is echoed by the strategic transition in Grace. In the first stage, Grace was encouraged by the great success of the famous 2S invention which reduced production cost significantly. Many process innovation projects were initiated and succeeded thereafter, but the potential of reducing cost by improving the process became more and more limited. After a period of succesful process innovation, Grace decided to invest more in product innovation, which was believed to be more profitable. The interplay between the technological innovator network (TIN) of Grace and the observed change in the innovation performance of Grace (in terms of the evolution of the indicators as well as the change in the balance of product and process innovation) is discussed next.

6.2 The evolution of the network structure of Grace's TIN and its impact on technological innovation

We can intuitively see the evolution of the TIN of Grace in three different stages from the snapshots shown in Figures 1–3 in which the ties that are

considered important or very important for innovation are plotted.[8]

The analysis of the sociogram is complemented with indicators of the structure of the TINs over the three stages presented in Table 3, which pro-
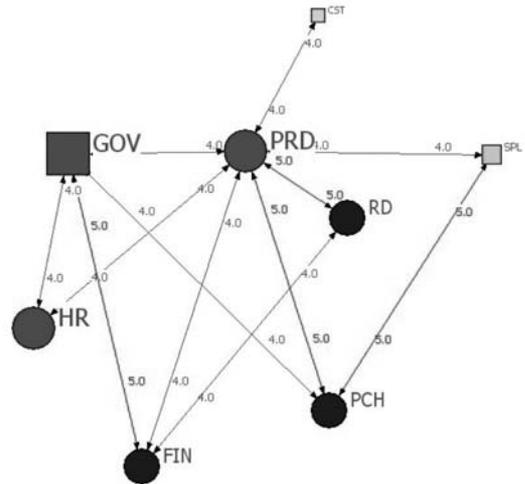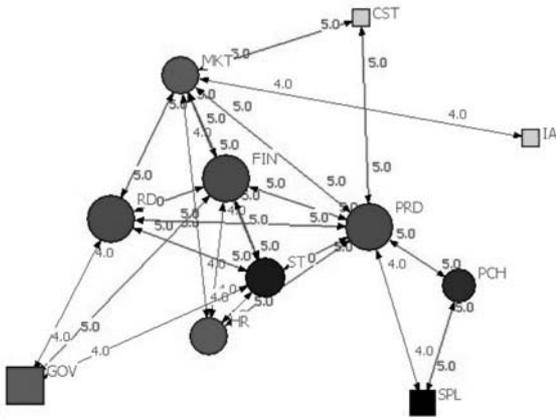

FIGURE 1: SOCIALGRAM WITH LINKS WEIGHTED OVER 4.0 OF TIN IN THE ELEMENTARY STAGE (1997–1999)

TABLE 2: TECHNOLOGICAL PERFORMANCE OF GRACE OVER TIME (1997–2007)

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Percentage of sales of new products as a percentage of total sales	1	1	1	1.4	8	37.4	9.3	19.9	51	45.8	47.8
Number of applied process innovation projects	3	4	18	74	81	32	37	32	40	35	34
d1 – efficacy index for product innovation	60.00	60.00	60.00	60.32	65.60	89.12	66.64	75.12	100.0	95.84	97.44
d2 – efficacy index for process innovation	60.00	60.51	67.69	96.41	100.0	74.87	77.44	74.87	78.97	76.41	75.90
D – Efficacy index for technological innovation	60.00	60.26	63.73	76.26	80.99	81.69	71.84	75.00	88.87	85.58	86.00

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[8] The shape of the nodes is related with their ID. The square shaped nodes are actors outside the firm while the round shaped nodes are actors inside the firm. The size of the nodes is related to their connectedness. The bigger the node the more connected it is in the TIN. Important and very important connections refer to those weighted 4 or 5 in terms of importance to technological innovation in the firm according to 5-level Likert item.

FIGURE 2: SOCIALGRAM WITH LINKS WEIGHTED OVER 4.0 OF TIN IN THE GROWING STAGE (2000–2004)
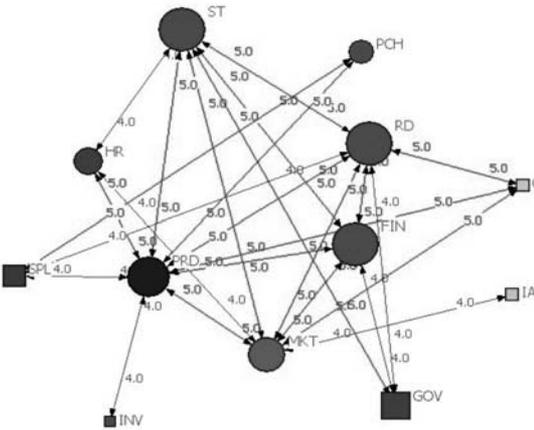
FIGURE 3: SOCIALGRAM WITH LINKS WEIGHTED OVER 4.0 OF TIN IN THE PLATEAU STAGE (2005–2007)

vides some interesting findings. First, the TIN of Grace became more connected and compacted over time. Second, it became larger and more diversified and third, it was inward-looking all the time. The implications that these changes in the structure of

the network had for the technological innovation performance of Grace are discussed next.

The TIN of Grace became more and more connected and compacted over the three stages of technological innovation.

The density of Grace's TIN increased significantly from the elementary stage to the growing stage and then increased slightly in the plateau stage (See Table 3). The performance of technological innovation in Grace became very significant in the growing stage compared to the elementary stage (see Graph 1). Then the performance reached another new peak and after that stopped growing in the plateau stage.

We attribute the success of technological innovation in the growing stage to significant and increased opportunity and frequency of interaction between people. This was confirmed by the interviews with the Grace president and managers. In 2000 Grace constructed a whole-people-participating internal technological innovator network. Employees from different functional departments with different knowledge and skills and were encouraged to talk to and work with each other. The project teams, which are distinctively new structures whose members are from different departments were created. These project teams are very flexible in size and functions. The hybrid-matrix-like project teams can be flexibly involved in big and small scale of innovation projects. In the same year Grace implemented another important policy called inside-out-and-outside-in policy with which outside experts were invited to the company for technological supervising or training, and inside employees were sent out to

TABLE 3: NETWORK PROPERTIES OF THE TIN OF GRACE OVER THE THREE STAGES

| | Density | | Centrality | Efficiency | |
	Avg. value	Std dev	Network centralisation	Average distance	Compactness
Elementary stage	0.6601	1.3439	32.08%	1.485	0.333
Growing stage	1.2745	1.6967	44.12%	1.434	0.696
Plateau stage	1.5294	1.7566	43.68%	1.451	0.775

visit companies or study in the universities. To support and coordinate technological innovation projects, the Science and Technology Administration Department (S&T) was set up in that year. The S&T Department, together with the HR Department, coordinated with different departments in arranging personnel for technological innovation projects, which were given different priority according to the firm's business strategy. Team leaders of the projects with high priority had the advantage of getting the particular people they wanted. As the S&T manager remembered:

> 'At that time S&T was a new department which was probably the first one in the chemical fiber industry in China. My job was to help people, from both outside and inside, connect to each other and work with each other. The outcome was great. We not only had good performance in technological innovation but also trained our employees.'

The further increase in density and decrease in network centralisation at the plateau stage, which meant more dense and more widespread interaction between actors, progressed with a further increase in technological innovation performance but the increase did not last long.

We attribute the plateau phenomenon to the S-curve of group learning. In an intensively connected network, there are stable relationships and mutual trust among actors[9]. However, when the intensive connections exist for a certain period of time, and when everybody knows more and more about what the others know, the interaction or exchange will become less and less productive and innovative. This may also be explained by the S-curve of group learning (Gersick, 1991). The explanation has been justified by the Grace managers. The vice president of production commented:

> 'Even though the statistics of technological innovation performance are still good in 2006

and 2007, we have already felt a kind of innovation fatigue. People are not as enthusiastic as before. When it comes to developing inside potential of the employees, it becomes more and more difficult. When it comes to cooperating with outsiders, the number of co-operations is increasing but the effects are still doubtable'.

Based on such observation in Grace, we argue that more frequent knowledge sharing and interactive learning result from a more connected and compacted network. In such a network more people can cross shorter social distances to learn from each other. When the connectedness of an organisational structure increases, it may indicate an increase of the extent of resource-sharing and cooperation (Powell et al., 1996). More frequent interaction between people provides more opportunities for organisational learning in the network, and consequently the performance of technological innovation is improved. But it does not necessarily mean that the higher the density the better it is. When density increases to a certain level, the effectiveness of the network in terms of knowledge sharing and technological innovation may go down because of the S-curve of group learning.

> The TIN became bigger and more diversified over the three stages of technological innovation.

The TIN of Grace has involved more actors since the growing stage – one more insider and five more outsiders joined in. Among the newcomers, the S&T Department (ST) is the only insider. It acts more like a knowledge broker than a knowledge resource for organisational learning in Grace. We observed that it has been in the core of TIN since its establishment in 2000. Its degree, betweenness, and closeness have been in the highest group (See Table 2).

The other five newcomers are all outsiders, namely industry associations (IA), consulting

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9   According to knowledge management theory, such a stable relationship and mutual trust is significantly important for sharing common standards and routines, which will further help exchange know-how and tacit knowledge among actors. The learning process is collective because it requires collaboration of different people with different capabilities and knowledge.

companies (CSL), legal services agencies (LAW), and private investors (INV), and competitors (CPT). The type of connection with these four outsiders is either open information sharing, which means accessing knowledge without the need to pay, or acquisition of goods, such as machines, patents, license, service, expertise, and so on. Although there has been no active participation in joint innovation projects with these outsiders, the connections with them are still important for Grace to enrich its knowledge base and foster its organisational learning, as these actors are of totally different background and specialty from Grace. But as the president of Grace commented:

> 'We learned something from our outside co-operators but far from enough. The effectiveness of learning depends on how much Grace could absorb and to what extent it is possible to develop common goals and find common interest between Grace and its partners'.

We argue that the diversity of actors provides an opportunity for diversity of knowledge sets for innovation. This is justified by the comments from the Grace managers that since the growing stage more outsiders have contributed to Grace's technological innovation by knowledge sharing and transfer, even though there have been no joint technological innovation projects with most of them; the exceptions are the customers and suppliers. But the extent to which this opportunity is fully deployed will be a function of the role that these external actors play in the network, as we will discuss next.

Most of the core members of the TIN in Grace are insiders and most of the outsiders are in the peripheral area over the three stages of technological innovation.

We conducted the core/peripheral analysis of the relational data over the three stages and obtained the results shown in Table 4.

The results are consistent with our observation that the overwhelming majority of technological innovations in Grace was from within the company. Although there have been several attempts in the past 10 years, there has not been even a single success in terms of a joint R&D program with social knowledge infrastructures such as universities and scientific research institutes. The outsiders have played roles of information transferring and knowledge sharing rather than knowledge creation. The only two exceptions are customers and suppliers. But their participation is still limited in terms of scale and scope.

According to the interviews, there are two possible explanations for why the external actors of the TIN of Grace play a very limited role.

From the regional perspective, the interviewers attributed the formation of the insider-dominated TIN of Grace to the distinctive geographical environment of Grace. Grace nests in the Sichuan basin surrounded by mountains in Southwest China. Sichuan is far from the economic, political and cultural centres of China, and Yibin, the city of Grace, is far even from the centre of Sichuan. Grace has to pay 500RMB per tonne more for transporting its products to customers than its main competitors because of its disadvantaged geographic location. Sichuan province ranked 21st among the

TABLE 4: CORE/PERIPHERAL ANALYSIS OF THE TIN OVER THREE STAGES (ACTORS WITH UNDERLINED NAMES ARE OUTSIDERS)

	Elementary stage	Growing stage	Plateau stage
Core actors	PRD GOV HR PCH MKT FIN RD LOG	PRD MKT ST FIN RD HR	PRD RD ST MKT FIN
Peripheral actors	SPL CST RI UNI	GOV PCH SPL UNI RI CST IA LOG CSL LAW CPT	HR GOV SPL PCH CST LOG INV IA CSL UNI RI CPT LAW

31 provinces in China in terms of GDP per capita in 2007.[10] This was its best performance for 10 years. While China's dependence on foreign trade stands at 70%, the corresponding figure for Sichuan is a mere 9%.[11] In China's economic landscape Sichuan is a relatively closed area rather than an open economy. Sichuan is considered to be geographically secluded, economically disadvantaged, and culturally self-enclosed. Things have improved in the past decades, but compared with other regions in China, especially the coastal regions, the progress is still too slow to create a fundamental change in its conditions. Therefore, it is relatively difficult for Grace to have a number of choices in accessing and forging strategic partnership with good consulting companies, legal service agencies, and private investors in Sichuan. It is also difficult to find some successful examples of strategic technological alliance in Sichuan to learn from. In other words, the technological distance between Grace and its local partner is high and therefore, the possibilities for the transfer of knowledge are limited.

From the industrial perspective, the interviewers attributed the feasibility of the insider-dominated TIN to the nature of the Chemical fibre industry in China, which is a traditional industry with mature production technology and dominated by homogeneous products. On the one hand, the R&D cycle is 12–24 months, which means technology does not change very fast. This gives space and time for Grace to train its own people and develop new technology in-house. On the other hand, in China's chemical fibre industry, innovation is something more about process than product. The main purpose of process innovation is to improve the performance of existing products and to lower the cost. When it comes to process innovation, it is more the work of the people who work in the production process

rather than a job for the researchers in the laboratory. In this sense, it is possible to have a productive innovator network which mainly consists of insiders. But a critical question is whether that structure can be maintained when the focus is not on process innovation but on product innovation. A deeper look into the positioning of actors may provide some answers to this question.

6.3 The change of the positioning of actors in the TIN and its impact on technological innovation

Table 5 presents the node properties of the TIN of Grace throughout the three periods.

The node centrality is the most frequently used parameter to measure the power of the position of an actor in the network. First, we discuss the change of the centrality of the four most centralized actors namely the production department (PRD), the R&D department (RD), the science and technology administration department (ST), and the marketing department (MRK). Second, we discuss the overall change of their centrality as a whole.

The production department (PRD) has taken the most central position in the core of the TIN of Grace over the three stages, but its position has slightly changed away from the very centre in terms of betweenness and closeness from the elementary stage to the booming and then plateau stage. The degree and Bonacich's power of the PRD department has been the highest among all the actors over the three stages of Grace (see Table 4). But its highest position in betweenness and closeness at the time of the elementary stage and growing stage was overtaken by RD and ST in the plateau stage. That means over the three stages, PRD not only has had the biggest number of connections with the actors in the network but also has been connected to the largest number of powerful actors in the network. But it is no

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[10] Statistical Communiqué of the People's Republic of China on the 2006 National Economic and Social Development http://www.stats.gov.cn/tjgb/index.htm
[11] Source: OECD Reviews of Innovation Policy: China 2008

TABLE 5: NODE PROPERTIES OF THE TIN OF GRACE IN THE THREE STAGES

	Nrm Degree			Nrm Bonacich's Power			Nrm Betweenness			Nrm Closeness		
	ELM	GRW	PLA	ELM	GRW	PLA	ELM	GRW	PLA	ELM	GRW	PLA
MKT	16.471	47.059	52.941	3.819	6.425	6.165	2.42	3.775	6.203	13.71	43.59	85
FIN	25.882	45.882	44.706	6.001	6.264	5.206	0.795	10.195	6.323	13.821	48.571	85
RD	18.824	44.706	65.882	4.365	6.104	7.672	1.445	8.732	11.813	13.821	48.571	100
PRD	42.353	64.706	69.412	9.82	8.834	8.083	7.926	8.67	8.014	14.05	48.571	94.444
LOG	14.118	11.765	17.647	3.273	1.606	2.055	0.808	0.315	0.672	13.6	39.535	68
PCH	25.882	25.882	25.882	6.001	3.534	3.014	2.136	2.565	1.768	13.821	42.5	70.833
HR	28.235	35.294	35.294	6.547	4.819	4.11	3.65	1.958	1.983	14.05	43.59	73.913
ST	0	47.059	64.706	0	6.425	7.535	0	3.257	11.813		44.737	100
RI	7.059	14.118	12.941	1.637	1.927	1.507	0.699	0.604	0.174	13.6	41.463	60.714
UNI	7.059	15.294	15.294	1.637	2.088	1.781	0	0.315	0.174	13.281	40.476	60.714
GOV	30.588	35.294	29.412	7.093	4.819	3.425	3.65	2.252	0.082	14.05	43.59	62.963
IA	0	12.941	16.471	0	1.767	1.918	0	0.092	0.082	0	36.957	58.621
CSL	0	10.588	16.471	0	1.446	1.918	0	0	0.174	0	37.778	62.963
LAW	0	9.412	7.059	0	1.285	0.822	0	0	0	0	36.957	54.839
INV	0	0	17.647	0	0	2.055	0	0	0	0	0	58.621
SPL	12.941	17.647	25.882	3.001	2.409	3.014	0	0.56	1.38	13.178	39.535	68
CST	8.235	14.118	24.706	1.91	1.927	2.877	0	0	0	13.178	36.957	60.714
CPT	0	7.059	8.235	0	0.964	0.959	0	0.092	0.082	0	38.636	60.714

* ELM represents elementary stage, GRW represents growing stage, and PLA represents plateau stage

longer the actor with the most opportunities to be a broker and no longer the closest to the others in the network in the plateau stage. PRD's central position is consistent with the core competence of low-cost-manufacturing based on technological innovation which we identified in our previous research, and with a technology strategy based on process innovation that characterised the elementary and growth stages.[12]

The marketing department (MKT) has been one of the core actors in the TINs over the three stages. Since the growing stage, the degree, betweenness, closeness and Bonacich's power of MKT have ranked in the top three (see Table 4) despite the fact that the increase of its centrality was not as good as those of RD and ST from the growing stage to the plateau stage. MKT has been an important knowledge broker between Grace and its customers. The information, such

as what the customers need, what the benefit and problems are when using the products of Grace, what suggestions they have for Grace to improve the performance of its products, is collected and conveyed by MKT. Grace's customers are mainly located in the east and south of China. MKT has the strongest connection with customers among all the other actors of the TIN.

The R&D department (RD) and the S&T department (ST) became more and more central over the three stages. The absolute number of degree, betweenness, Bonacich's power, and closeness of RD and ST kept increasing throughout the three stages. The rank of the degree, betweenness, Bonacich's power, and closeness of RD increased over the three stages. The rank of the degree and Bonacich's power of ST remained the same since it was established in the growing stage, while its rank of betweenness and closeness increased.

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[12] See Liu et al.'s working paper 'Building technological-innovation-based strategic capabilities at firm level in China: a case study of a textile company'

To summarize, first, we observe a continuous increase of degree, betweenness, and closeness centrality of almost all the inside actors over the three stage. The only obvious counter change happened to Financial Department (FIN). But according to our investigation the function of FIN in technological innovation is mainly collecting and sharing financial information. So the change of the centrality of FIN did not have a significant influence on organisational learning for technological innovation in the TIN. Second, we find a change in the relative position of the four key actors. RD and ST took the central position in betweenness and closeness. They also had a significant increase in both degree and Bonacich's power while the most centred PRD just had a slight increase in degree and even a decrease in Bonacich's power.

It is interesting to see the delicate change of the relative positions of ST and RD on the one side and that of PRD and MKT on the other side. By comparing graph 1 and graph 2, we find that when the centrality of PRD and MKT is higher than that of the ST and RD, the performance of process innovation is mostly better than the product innovation. When the centrality of ST and RD is higher than the PRD and MKT, the performance of product innovation is mostly better than that of the process innovation. This is a very interesting finding.

When it comes to technological innovation activities, ST and RD were more concerned with science while PRD and MKT worked more on obtaining experience. Product innovation in the chemical fiber industry is more science-based and the process innovation in the industry is more experience based. Savory (2006) distinguishes between innovation led by formal R&D efforts and more 'practice-based' innovations which are the result of staff developing ideas and inventions in the course of their normal work and the result of an organic and emergent process. The features of practice-based innovations include knowledge produced in the context of application, trans-disciplinary, heterogeneity of sites in which knowl-edge is produced, social accountability and reflexivity (Nowotny et al., 2003). This distinction is echoed by the identification of STI and DUI modes. Jensen et al. (2007) identify two modes of learning for innovation, namely the STI mode and the DUI mode. The Science, Technology and Innovation (STI) mode is based on the production and use of codified scientific and technical knowledge, and the Doing, Using and Interacting (DUI) mode is an experienced-based mode of learning. We categorize the roles of ST and RD as STI or practice-based innovation mode, and the roles of PRD and MKT as the DUI and practice-based innovation mode.

We argue that in the TIN, the more central the actor is the more interactive learning the actor does, and the better technological innovation performance related to this particular actor the TIN has. When the company adopts the process innovation based strategy, the PRD and MKT become the core actors. The learning that occurs in the TIN is mainly of the DUI mode. When the company adopts the production-innovation based strategy, the RD and ST become the central players in the TIN. The learning occurs in the TIN shifts to the STI mode. The question is whether a product-innovation based strategy can be supported by an inward-looking TIN.

> The change of the positioning of actors outside the firm and its impact on technological innovation.

The centrality of the actors outside of Grace mainly increased over the three stages. The only significant decrease in centrality happened to the government (GOV). Government was the only outside actor in the central area of the TIN with continuously strong ties with Grace's inside actors.

Government was the core actor in the elementary stage from 1997–1999. Since then government has been moving out of the centre of the TIN. Its degree, betweenness and Bonacich's power mainly decreased continually. It gives us an impression that in general the centrality of the government decreased over the three stages. But

we should be careful when explaining the network dynamics only by the degree centrality measures, because they only take into account the immediate ties that an actor has, or the ties of the actor's neighbours, rather than indirect ties to all others. We see in Graph 3 that the closeness of government increased significantly throughout the three stages which meant the government had shorter distance to the rest of the actors in the TIN. Closeness centrality approaches emphasize the distance of an actor to all others in the network. Combining the analysis of both degree centrality and closeness centrality, we find that government had less direct connections but more indirect connections since the growing stage. In other words, the government became less central in a local neighbourhood but more connected to the network as a whole. The change in the pattern of connection was justified by the comments of the Grace managers and a director of the Economy Committee of Yibin City. After 2004 the local government decided to adjust its role from a supervisor to a supporter. Government tended not to directly interfere in the daily operation of the state-owned company but indirectly back them up, such as provide favourable policy and legal support. In this sense, government had less direct connection within the network but was closer to all the actors in the network. Grace considered the support of the local government to be one of the most important factors for its success.

Universities and research were truly sidelined in the TIN of Grace during the three stages in the past 10 years. Centrality of universities was kept in the lowest group (see Table 3). Research institutes were also in a similar position. In Sichuan province, where Grace is located, there is a research institute specialized in textiles, a textile school that is part of Sichuan University, a textile college and many other universities. But the cooperation with research institutes was mainly limited to open information sharing and acquisition of goods, such as service, software and expertise, and so on during all three stages.

Grace's cooperation with universities was also limited to recruiting university graduates in the elementary stage plus sharing technological information in the booming and plateau stages. Grace gave up R&D cooperation with universities after a failed attempt in 2002. In 2007, Grace began to have joint programmes with universities and research institutes, but the scale and scope of the cooperation is still very limited and the company is still very cautious with such programmes.

Customers (CST) and suppliers (SPL) also have strong ties with Grace's inside actors. Even though these two actors have never been in the central area of the TIN of Grace, the exchange between Grace and CST and SPL is important to technological innovation. The connection between Grace and its customers and suppliers included all three kinds of connection, namely open information sharing, goods acquiring, and innovation cooperation. The knowledge and information from these two actors are crucial to both the input and output of the TIN.

In summary, the low profile of external actors in the network was compatible with the process-based technological strategy that was dominant in the first years of the analysed period. This peripheral character of the external actors has not changed over time. While there, the external actors in the network are more varied; they play a marginal role.

Combining the analyses of both external and inside actors, we may argue that when Grace shifted from a process-innovation based strategy to a product-innovation based one, the learning mode shifted from DUI mode to STI mode. In the STI mode of learning, the external linkages with knowledge infrastructures are all important. In the case of Grace, when the firm's technological innovation strategy shifted, its TIN did not change accordingly from introverted format to open structure. That is the reason for the technological innovation fatigue with which the performance of technological innovation stopped growing at the plateau stage.

7. CONCLUDING REMARKS

This paper examines the dynamics of a technological innovator network of a state-owned textile company in underdeveloped southwest China to see how the structure of the TIN has evolved in the past 10 years and what impact it has had on the technological performance of the firm.

The analysis shows that changes in the configuration of the TIN over time have had an impact on not only the amount of technological innovations but also the predominant type (product vs. process innovations) of technological innovations.

From a theoretical perspective, our findings confirm that the connectedness of the network is positively related to technological innovation performance, but the relation is not linear. More connected and compacted networks result in more frequent interactive learning because more people can cross shorter social distances to learn from each other. When the connectedness reaches a certain level, interactive learning will be less and less efficient due to the S-curve effect of group learning. Then, the technological innovation performance of the TIN may stop growing or grow at a lower rate. Higher centrality of an actor is related to more interactive learning of this particular actor in the TIN.

The more central the actor the more interactive learning the actor experiences, and the better the technological innovation performance related to this particular actor the TIN has.

As the firm moved from a process-oriented strategy towards a product-oriented strategy, the TIN became more connected and compacted, and more diversified, but has always been inward looking with the external actors staying in the peripheral area. The roles that different actors play in the network also changed over time. The absolute predominance of the production department was substituted by a more prominent role of the R&D department and the S&T administration department in the later stages.

A predominantly inward looking TIN is consistent and may be adequate for a process-based technological strategy, particularly in the textile industry. Process innovation is likely to occur through learning-by-doing and, in the textile industry, this mainly occurs in the production department. The centrality of the production department is also coherent with this form of strategy.

The alignment between technological strategy and structure of the TIN led to an extraordinary success in process innovation.

However, our analysis shows that changes in the technological strategy need to be fitted with a transformation of the structure of the TIN. Although the managers of Grace have argued that the configuration of the TIN has always followed the technological strategy of Grace, our analysis shows that it has not been the case. The central roles of the R&D department and the S&T Administration office suggest a move towards a more science-based and product based strategy. This type of strategy is founded on a substantially different mode of learning – STI mode of learning as opposed to learning by doing.

In this mode of learning, the external linkages with knowledge providers are fundamental.

But these external actors are only peripheral and play a very marginal role in the TIN of Grace, which could explain the technological fatigue observed by the managers at Grace.

In sum, inward looking, production-centred TINs are adequate for a process-focused technological strategy, but they are not enough for the product and science-based strategy that Grace wants to pursue. For that, the firm needs to develop stronger ties with external networks.

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