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Networks as sponges: International collaboration for developing nanomedicine in China

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ABSTRACT

Previous research tended to emphasize the benefits of international collaboration. This emphasis has led to a common belief that international collaboration will necessarily enhance productivity in science, innovativeness, and even societal impact. Yet, benefits and costs are relative. Economic actors and scientists do not perceive benefits in the same way in all contexts, and there are situational barriers to overcome for materializing the benefits of collaboration. This study examines the case of Chinese science actors who develop medical applications with nanotechnology, and highlights the "barriers to networks" when scientists attempt to collaborate overseas for an emerging technology. I present my findings with the metaphors of "pipes", "prisms", and "sponges", and propose a framework for evaluating the utility of international collaborative networks.

1. Introduction

Previous research emphasized the desirable effects of network connectivity. Yet, as research evidence accumulates, the literature has shown that network benefits are conditional upon a myriad of factors. With respect to performance, networks can increase an actor's information search capacity (Granovetter, 1973), creativity (Powell et al., 1996), and productivity (Fernandez et al., 2000). But these benefits depend on mobilizing the appropriate network(s) at the right time. The distribution of network benefits is another important issue worthy of consideration. When two or more actors are connected in a network, not all of them may yield the same level of benefits, if at all. At any given time, the benefits may only be felt by some members in the same network (Smith-Doerr, 2005).

There are strong motivations to study the conditional nature of network benefits: first and foremost, as network benefits may be felt, perceived, and realized differently in different situations (Casciaro et al., 1999), it is useful to reveal how the utility of networks matches with specific contextual needs and institutional conditions (Luk et al., 2008). The findings would help practitioners better understand the range of network benefits and utilize them appropriately. Second, as Miles and Snow (1992) pointed out, network forms of organizations are subject to failures in several ways. Among other things, network partners may be unable to handle network traffics at times of "overflow" or "congestion". To capture how organizational actors may utilize networks flexibly to avoid or mediate network failures, it is essential to follow their actual work process (Latour, 1988; Fujimura, 1996).

Specifically, this paper develops the metaphor of "sponges" to complement two older metaphors of network benefits—pipes and prisms—in the literature (Podolny, 2001). Podolny's conceptions of pipe and prism are quite clear in their meanings. Pipe refers to a network structure that allows resources to flow from one party to another. Prism refers to a network structure that allows light to shine from one party on the other, making the latter glow in colors. Quite generalizable as these two metaphors may be, they do not adequately capture the flexible and voluntary nature of many network activities in action (Jones et al., 1997). To fill this gap, sponge can be construed as a flexible network structure that absorbs fluid materials from all sides and, with constructive efforts of network partners, squeeze out the useful materials at a later time. Like other metaphors, the use of sponge would not capture the full range of network benefits. Yet, it highlights several salient issues of network benefits for inter-organizational exchanges. Most importantly, I emphasize that networks provide opportunities for organizational actors to engage in learning-by-doing (Argote, 1999; Beckman and Haunschild, 2002; Irwin and Klenow, 1994). My findings are also concerned with how network partners of unequal power could benefit from the spongy nature of networks differently, and address failures of networks as pipes and prisms with different degrees of success.

The empirical case of this study focused specifically on Chinese academic institutes and their scientists who utilized international networks to develop nanomedicine (medical products enabled by nanotechnology research). Nanomedicine includes such products as gold nanoparticles inserted into human bodies to prevent

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cancer cells from multiplying (Kang et al., 2010). Although these nanomedicine products had great potential therapeutic value, the technology was still nascent among scientists—many of them continued to view nanotechnology with great uncertainty (Roco, 2007). In China, some scientists view nanotechnology and nanomedicine as opportunities to elevate the nation's science and technology status (Leung, 2012a,b). Yet, the technical infrastructure is still underdeveloped in China. Can they benefit from international networks for learning-by-doing? Can these networks be conceptualized as sponges?

To answer these questions, this research adopts a hybrid approach that combines quantitative and ethnographic research. This approach is useful in generating conceptual frameworks, and propositions for testable hypotheses (Harrigan, 1983). I analyzed quantitative data to identify high-performance Chinese institutes in nanomedicine research, and utilized ethnographic data to reveal Chinese scientists' perceived benefits of international networks. Based on my observations, Chinese science actors had mixed feelings regarding international networks. Interestingly, those who benefit from networks the most placed a great value on the ongoing relationships that they develop with international colleagues, much more so than the short-term, immediate "publication" or "prestige" gains, offered by networks. This is not because Chinese science actors neglect the impacts of publications or prestige; in fact, these achievements have become important criteria for career advancement in the Chinese high-tech sector nowadays (Leung, 2008). The more important reason, according to many of my interviewees, is that "China has to rely on its own" in the long run. They view overseas networks as capitals for learning and long-term development, rather than assets to acquire short-term gains.

The following discussions summarize the relevant literatures from organization theory and science studies that orient this research. My emphasis is that the utility of networks requires different parties to perform mutual adjustment to align multiple interests over time (Latour, 1988; Fujimura, 1996). I also outline a number of important changes in the Chinese high-tech sector to contextualize my research findings. Then I explain strategies of data collection and analysis, and propose a framework of evaluating costs and benefits of networks. Towards the end, I further discuss the implications of my findings.

2. Literature

2.1. Network benefits: pipes and prisms?

In the literature, Podolny generalized network benefits with the metaphors of "pipes" and "prisms" (2001). This framework assumes that two major sources of uncertainty prevail in market transactions, which may be reduced by utilizing external networks. That is, economic actors face "ego-centric" uncertainty (about themselves), and "altercentric" uncertainty (from others). Ego-centric uncertainty arises because of resource constraints, and/or other task-related difficulties. For example, an individual entrepreneur might be uncertain about the firm's resource capabilities. To remain competitive (or simply survive), s/he needs resources. Yet, s/he might use up all resources at unpredicted times, and lack the capacity to re-generate resources. External network ties provide an accessible channel where critical or supplementary resources can become available in times of need.

Alter-centric uncertainty is concerned with social acceptance or expectation from other actors. For instance, the same entrepreneur (or his firm) is facing a group of skeptical customers, who worry that the firm is unable to serve their needs well. By building networks with other reputable firms, the entrepreneur is able to restore the confidence of his customers. Moreover, other firms in the market may develop great trust with the entrepreneur or the firm. In Podolny's conception, networks as pipes (to transfer resources) enable the focal actor to reduce ego-centric uncertainty; networks as prisms (to share reputation and trust from others) enable the focal actor to reduce alter-centric uncertainty. The unit of analysis does not have to be individuals. It can be the entire organization.

The metaphors of pipes and prisms are quite appropriate for explaining why Chinese scientists seek international network partners. First, international networks are useful information and knowledge pipes for Chinese science institutes. In the literature, Granovetter (1973) showed that network ties enhance the information-seeking capability of job seekers to identify potential jobs. Networks can be regarded as information pipes in this context. In the case of Chinese science institutes, information about the latest development of nanotechnology and nanomedicine was still quite limited. International networks functioned as pipes of information and knowledge resources, which were essential to developing something as high-tech as nanomedicine.

Kostoff et al. (2006) adopted a bibliometric approach to show how Chinese science institutes obtain prism value from international networks. According to their findings, collaboration between American and Chinese scientists benefits the latter group at the expense of the former. That is, American researchers had generally achieved high impact scores in publications than their Chinese counterparts. As such, scientific teams of "American researchers only" outperformed those teams having both American and Chinese researchers. Also, since "US-China" teams outperformed the teams of "Chinese researchers only", Chinese research teams essentially enjoyed a net "prism" gain by collaborating with American teams in publishing. At the same time, the American teams had to bear a "cost of impact score" to collaborate with Chinese researchers. These research findings are intriguing by themselves. But more importantly, they suggest that collaborative parties may be "unequal" in terms of expectations, cost-benefits calculations, and even negotiation power (Spencer-Oatey, 1997). This point will be further discussed below.

2.2. Conditional network benefits

The utilization of international networks can be quite different in specific cases, even for science actors within the same national setting. The literature contains empirical evidence about possible variations. For example, in Granovetter's job search study, his specific results showed that "weak ties" (distant friends and relatives of the job seeker) were more useful than "strong ties" (close friends and relatives that share the same social circles) in providing information to job seekers. Bian and Logan (1996) pointed out that the relative utility between weak and strong ties varies across socio-economic contexts. In their research, weak ties did not provide useful information for job seekers in the transitory Chinese economy. Contrary to Granovetter's findings, Bian and Logan believed that valuable information could only transfer through strong ties of Chinese job seekers. In other business contexts in China, networks "may not work" in ways similar to those in Euro-American settings (Xiao and Tsui, 2007).

More recently, Luk et al. (2008) demonstrated that social network does not confer the same type of benefits to organizational actors in different institutional contexts. In market economies, social network provides useful informational benefits—many of them are benign. In transitional economies, however, social network may create particularized trust and other malignant effects. In other studies, researchers found that the costs of networks outweighed the benefits. For example, new immigrants without family ties might turn to local ethnic communities for material assistance and moral support in their initial years in the U.S. (Portes and Sensenbrenner, 1993). Yet, some of these immigrants might become overly embedded in ethnic networks, gradually lost their autonomy, and became unable to assimilate with the mainstream. Because of resource constraints, Chinese science actors take costs and benefits seriously in research activities. Their cost-benefit calculations would likely influence how they strategize to build and maintain international networks (Leung, 2012b).

Gulati's study emphasized the importance of time with respect to the realization of network benefits (Gulati, 1999). Since organizations accumulate network resources over time, they tend to show time-specific network preferences and adopt alliance behaviors accordingly. This finding pertains to networks linking organizations of unequal power (Contu and Willmott, 2003; Cumbers et al., 2003). For example, an organization in need of certain information at one time may network with another organization specifically for acquiring information resources. At other times, the two organizations might expect different things from each other, and yield different benefits. For example, Chinese science institutes may now build network ties with Euro-American science institutes primarily for information and material benefits; whereas their international network ties may seek Chinese institutes mostly for entering the Chinese consumer market (Xiao and Tsui, 2007).

Also, it is important to consider the process in which network partners of different powers absorb "pipe" or "prism" benefits from each other. In this respect, an ethnographic approach is able to show what low- and high-power organizational actors actually do in the process of seeking network benefits from each other (Fujimura, 1996). Based on my observations, a significant part of network benefits for Chinese science actors is the availability of network partners itself. This availability of networks allows them to gradually find out what possible benefits exist, and how these benefits may be materialized. More generally, forming a network tie with another organization may not bring about immediate benefits. Instead, the organizational actor needs time to learn about its network partners after the network has been in place (Beckman and Haunschild, 2002).

Learning may be ongoing while the organizational actor has already engaged in joint ventures with its network partner(s) (Van De Ven and Polley, 1992). In learning process like this, the actor's flexibility and voluntary actions are essential (Beckman and Haunschild, 2002; Cumbers et al., 2003). My emphasis on networks as sponge intends to highlight the possibility of international networks as a flexible learning-by-doing platform that enables organizational actors to experiment different strategies, and draw on useful resources (and fame) from network partners gradually (Argote, 1999; Irwin and Klenow, 1994).

2.3. Mutual adjustment and network benefits

In social studies of science, researchers pay attention to how science actors mobilize networks to align different interests relevant to the actual process of science-making. Latour's masterful work on Pasteur shows us how science actors purposefully enroll others to create a network, manipulate inscriptive devices, and establish the legitimacy of scientific theory and measurement tools (Latour, 1988). The process of "network enrolment" takes time and delicate effort, and only the most "artful" scientists with the ability to align multiple interests can succeed at the end.

Callon's research on the collaboration between fishermen and scientists offered another interesting perspective (Callon, 1986). Accordingly, network enrolment may be a two-way (or multiple-way), mutual process. Under this logic, the success of a network depends on all its partners, not a single actor. A rigid network structure is unlikely desirable for its members. Instead, a more flexible network structure—such as a sponge—may better serve the need of mutual enrolment among network partners. Fujimura's research on the emergence of molecular biology offers a great example (1996). To put forth a new discipline such as molecular biology in the 1970s, science actors skillfully exploited the amorphous nature of molecular biology to align academic, commercial, and political interests. The network of molecular biology did not simply provide its members pipe or prism benefits. Rather, the network is a locus of actions, mutual adjustment and learning. And the success of molecular biology did not happen overnight but spanned over decades.

Seen differently, networks provide more than "one-time" benefits (such as getting a job) if organizational actors can identify what benefits their networks can offer and utilize these benefits properly. For example, it is generally believed that new employees with friends and relatives working in the same organization are able to adjust to the new environment more effectively due to pre-screening (prior to taking the job), and personal advice (after taking the job) (Fernandez et al., 2000)—both of which require the new employee to be active in learning about the utility of their networks. At the firm level, there are other resource benefits from external networks, but they accrue to the focal actor over time. For example, intimate business partners may offer some flexibility with respect to delivery time, payment terms, and other economic transactions (Uzzi and Spiro, 2005). These benefits are significant, and embedded in the ongoing networks of business enterprises.

While some resources can be transferred from one individual (or organizational entity) to another relatively easily, other things such as reputation, legitimacy, status or trust cannot be "shipped" easily. Sufficient time is necessary for transferal of these and other resources. Often, for an organizational actor to benefit from its network ties, the focal actor needs to develop a close attachment with the desired network(s) to find out what actual benefits can be derived. For example, a firm seeking to increase its status by forming a partnership with another prestigious firm in the market needs to learn what its reputable status can actually increase business opportunities, market share and business performance in general.

2.4. International networks and nanotechnology in China

To understand how Chinese science actors perceived and utilized international networks, a brief overview of the Chinese high-tech sector is in order. China has experienced a long history of economic underdevelopment since World War I (Fairbank and Goldman, 2006). Political conflicts and other economic problems within the country, including the notorious Cultural Revolution, had made Chinese political leaders extremely eager to strengthen the country (Ding, 1994). Science and technology development has always been a top priority item in China's national developmental plan (Cao et al., 2006). As the Chinese economy prospered in recent years, Chinese political leaders have expressed increasingly strong sentiments to become a recognizable world superpower in high-tech science. Investments to scientific research in absolute dollars have increased steadily (State Statistical Bureau of the PRC, 2006).

Following the lead of industrialized countries such as the U.S., Japan and other European countries (Roco, 2007), Chinese political leaders pledged a large amount of government investment for nanotechnology research since the year 2000 (Bai, 2005). It is believed that nanotechnology is "new to everyone", so China could be on par with others in this new high-tech area more easily. Yet, the level of public investment in nanotechnology in China was less than 20% of that in the U.S., as of 2006 (Roco, 2007; Leung, 2008). To engage in a new science that requires a high level of R&D inputs, the Chinese government believes that collaborative and knowledge networks—particularly ties with overseas Chinese scientists—can be very useful (Zweig et al., 2008). The government provided funding for forging international partnerships, and international collaboration in nanotechnology research has increased rapidly since 2000 (Bai, 2005).

As Chinese scientists had to overcome both ego-centric and alter-centric uncertainty in the market of nanotechnology and nanomedicine research, many of them built international networks to foster information exchanges, sharing facilities, coauthoring in scientific publications, informal contacts and even formalized institutional partnerships. In addition to resource deficiency, Chinese science institutes suffered from a low perceived status in scientific products. In particular, Chinese scientists affiliated with academic institutes of low status had to overcome substantial trust barriers to publish in Euro-American journals and magazines (DiTomaso et al., 2007). More generally, academic institutes sought to raise their status by partnering with high-status ones. Collaborating with a high-status institute in Euro-American countries is often regarded as an effective means to raise one's visibility, very much like lining up with a "prism".

The metaphors of pipes and prisms focus attention on outcomes. Yet, networks also facilitate the process of innovation, research and other management activities. Like other science actors, Chinese scientists often pick up the "best practices"—and the associated satisficing outcomes—through actually doing the task. Argote called this "learning by doing" (Argote, 1999). Knowledge and collaborative networks produce ongoing relationships between Chinese science actors and their network ties—or the opportunities of learning by doing. Van De Ven and Polley (1992) have found that learning occurs quite often during—rather than after—the process of organizational innovation. Given infrastructural constraints and economic underdevelopment, Chinese science actors are likely to place strong value on international networks as learning platforms.

3. Methods

This research combines analysis of available quantitative data from different sources, and ethnographic data from interviews and participant-observations. Such a hybrid approach in data collection is suitable for studying innovative activities in rapidly changing socio-economic contexts such as China (Harrigan, 1983), but the researcher needs to remain organized throughout the research process to utilize the hybrid approach effectively. My quantitative data come from published papers, professional reports, and statistical data published by Chinese government agencies. Some of these data have been analyzed extensively already; others have not. Ethnographic data come from face-to-face and virtual interviews with Chinese and American scientists, as well as observations based on participating in professional meetings, laboratory tours, and other less formal meetings. Interviews had taken place in my interviewees' offices, conference halls, other locations and over-the-phone. In terms of participant-observations, I went to some of the professional conferences and seminars that my interviewees attended. After these observations, I followed up with my interviewees and asked them what they had learned, whether they achieved their objectives, and so on. These discussions were very useful for me to better understand my interviewees.

With respect to costs and benefits, I have performed a Data Envelopment Analysis (DEA) to evaluate networks and funding as input factors, and publications as output for the most prolific institutes identified in the literature review. My DEA findings enabled me to ascertain what the top Chinese institutes were, to serve as the focus of my ethnographic research. As this paper uses DEA primarily for identifying top Chinese institutes, and the findings concentrated on the ethnographic part, I omit the actual formula and computations associated with DEA here. Van de Ven et al. (2011), Leung and Pasupathy (2011) and others provide more discussions on the technical aspects of DEA.

Given that Chinese science actors constitute a big population, I followed a purposive data collection strategy in ethnographic research. My focus was on the most prolific and high-profile Chinese science actors in nanomedicine research. Table 1 summarizes the number of interviewees from different academic institutes. While this focal group differs from Chinese science actors working in less prestigious institutes, I interviewed a small number of Chinese scientists from outside the focal group. The rationale is to better understand how the work of Chinese science actors might differ in alternative settings. In short, my data collection strategies are intended to be focused, and to avoid unnecessary distraction (Table 1).

Table 1
Institutional affiliations of seventy interviewees.

Institute	Number of interviewees
Tsinghua University	14
Peking University	11
Chinese Academy of Science (selected institutes in Beijing and Shanghai)	14
Fudan University	9
Others (China/Hong Kong)	14
Others (USA)	8

My interviewees included seventy research and teaching faculty members from academic institutes, students, business executives and related staffs in the U.S. and China. The majority of interviewees were from China. In the U.S., I have included Chinese and non-Chinese interviewees. When analyzing interview data, I pay attention to the interviewees' academic affiliation, research interests and other demographic information. This information allowed me to better evaluate the genuineness of interview data. Interviewees that did not participate in the research at sufficient length were dropped from the analysis.

4. Findings

In 2005, Chinese scientists produced 18% of the world's nanotechnology research articles (Kostoff et al., 2006). This productivity figure draws data from the Scientific Citation Index (SCI) database, and does not include many "home" or Chinese-written journal papers that were unrecorded in SCI. Of these research articles from Chinese scientists, over 90% of them were coauthored papers. International collaborations enhance the prestige of Chinese science actors in terms of publication. According to Kostoff et al. (2006), "China-only publications" (research publications with authors from China but no other countries) had a median citation of 4 (which means that only four other scientists cite a Chinese paper on average). In comparison, the median citation was 12 for "US-only publications". For "US-China publications", the median citation was 10. In nanotechnology, Beijing and Shanghai were the most productive and influential ones (Kostoff et al., 2006). My DEA results identified top science institutes in China with funding and publications as inputs and outputs respectively (Table 2).

The most prolific institutes were from Beijing and Shanghai. These two cities were where I conducted most of the participant-observations and in-depth interviews. These ethnographic data reveal the subtleties regarding the beneficial effects of, and resistance to, international networks.

4.1. Networks as pipes

The importance of information for Chinese science actors should be understood in view of the infrastructural constraints within the local Chinese research environment (this is mostly referred to mainland China, excluding Hong Kong, Taiwan and Macau). As mentioned, although the Chinese government has increased its

Table 2
DEA ranking of Chinese science institutes based on funding, publications and citation score in nanotechnology research, 1999–2003.[a]

Rank	Institute
1	Chinese Academy of Sciences
2	Tsinghua University
3	Peking University
4	Nanjing University
5	University of Science and Technology China
6	Fudan University
7	Jilin University
8	Shandong University
9	Zhongshan University
10	Tianjin University
11	Zhejiang University
12	Nankai University
13	Harbin Institute of Technology
14	Wuhan University
15	Shanghai Jiaotong University

[a] Data come from various publications and publicly available sources (e.g. Kostoff et al., 2006; State Statistical Bureau of the PRC, 2006).

funding to scientists in recent years, most Chinese scientists still face significant budget constraints in comparison with their counterparts in industrialized countries such as the U.S. (Leung, 2008). Some of my interviewees suggested that being updated about the latest development in certain foreign labs is an economical way to keep Chinese research current. For something as new as nanotechnology, this type of foreign information is preferred to the traditional research orientation of a "closed-door" policy. Information is regarded by my interviewees as essential to exploration and exploitation in nanotechnology research (more discussions on this point below).

The use of information and communication technologies (ICT) has facilitated information exchanges between Chinese science actors and their overseas ties. Advancement in ICT has kept the cost of long-distance communication very low and convenient. In effect, ICT helps ensure that scientists from Chinese institutes have repeated and ready access to knowledge and information from different collaborative networks. For R&D problems that were particularly difficult to resolve, Chinese scientists might even need to engage in multiple back-and-forth discussions and information exchanges with their ties.

One of my interviewees in Beijing was a young chemistry professor from a prestigious university in Beijing. His research was concerned with nanomaterials for medical applications. Since he had published relatively frequently in top science journals and magazines such as *Science* and *Nature*, he was highly regarded in his institute. This scientist emphasized that international networks served mainly as information pipes. For him, international networks of scientist colleagues helped him filter information on Internet: as he put it: "the leading colleagues in the field have all opened groups on the web. Visiting these websites allows us (Chinese scientists) to understand what they (foreign scientists) will do in the coming half a year, what they are doing now and what they may do, what areas cannot go further". This scientist expressed his preference of developing nanomedicine "by himself", rather than actually working with a foreign scientist. Besides, he did not see networks as having significant values in terms of enhancing prestige.

Still, this scientist recognized the importance of developing long-term relationships. In some occasions, long-term relationships bring useful information to the scientist without him actively seeking. As he recalled: "Sometimes they (international colleagues) call to greet us. We will ask about what they do". According to him, the international colleague has to trust him enough to share really useful information about scientific research. This trust requires many years to build and maintain. Other Chinese scientists who maintained close relationships with international colleagues could even borrow high-ended equipment for research purposes.

4.2. Clogged pipes

But not all information is equally valuable. Because of time constraints to process and utilize information, the science actor needs to carefully select what information (or resources) to seek and what networks to mobilize at different times. For many of my interviewees, information from local networks was not very useful because it was "available anyway". Some of my interviewees actually had to reduce "social exchanges" with local colleagues to save time for research and teaching. Information provided by networks from abroad often had a higher value. But getting this information entailed increased communication and traveling costs, which possibly outweigh the benefits of academic collaboration. In other situations, my interviewees sought advice and help from international colleagues but never got a reply. They gradually lost faith in international networks. In practice, collaborative nanotechnology research between Chinese academic institutes tends to involve researchers from the same or adjacent region(s), and international collaboration has remained a small proportion out of all collaboration activities (Kostoff et al., 2006; Leung, 2012a).

Besides, even though ICT can save communication costs in theory, the Chinese government has prohibited internet access to some foreign websites for political reasons. It is believed that controversial issues—including high-tech science news—posted in foreign websites could generate social unrest in China (Cao et al., 2006). Therefore, even with useful information value, foreign sites might be banned temporarily or permanently by government agencies. Some social media websites that allowed scientists to communicate informally, such as Facebook, cannot be used in mainland China (but accessible in Hong Kong, Taiwan, and Macau) (Wall Street Journal, 2010). In addition, emails between certain Chinese scientists (who work in "classified areas") and their international colleagues may be monitored or censored by the government (Kalagas, 2008). In consequence, information networks for Chinese scientists may be "clogged", and might not generate useful value to Chinese science actors.

Despite various forms of internet censorship, contacts with the outside world have become much easier for Chinese scientists in recent years. Some Chinese internet users employed technology to overcome firewall or other blocking devices by Chinese government agencies (Wall Street Journal, 2010). Besides, foreign colleagues with long-term relationships are willing to share information in international conferences, professional meetings and other private occasions. More formally, investors, foreign scientists, multinational technology corporations (such as Microsoft and Facebook) which have recognized the economic prospect of China in science and technology have initiated partnerships with Chinese partners. These efforts have enabled Chinese science actors to acquire information and other resources from international collaborators.

4.3. Networks as prisms: enhancing prestige

To Chinese science actors, partnerships with international collaborators are desirable not only for addressing resource uncertainty. As mentioned earlier, reputational enhancement is equally important. For example, the Tsinghua-Foxconn Nanotechnology Research Center was set up in 2002 (Tsinghua University Education Foundation, 2009), which fulfilled the prestige needs for both partners well. Through this partnership, the FoxConn Technology Group consolidated its renowned status as a high-tech manufacturer. FoxConn continued to get business from multinational companies such as Apple Computer. The academic partner—Tsinghua

University—also benefitted. The monetary investment provided by FoxConn enabled Tsinghua to hire a large group of competent scientists to conduct nanomedicine and other nanotechnology research. These scientists enjoyed the reputation of working with FoxConn.

There was also "prism" value for individual scientists. Two of my interviewees benefitted from each other in nanomedicine research. These two scientists—one from the U.S. and the other one from China—sought to produce nanomaterials for biomedical applications such as tissue engineering. While the two of them were already quite established in medical research, nanomedicine was new to both of them. Thus, they needed help from other scientists. In the beginning, their collaboration was like other common collaborative activities in scientific research, without much public attention. Yet, over time, the two started to engage in more frequent information exchanges, including visiting each other's campus and teaching graduate students. While both of them were affiliated with a very prestigious academic institute in their own country, their collaboration soon caught media attention. Their story was covered in newspapers and scientific magazines. The Chinese scientist—with visiting professorship in a prestigious American institute—won respect from other scientists in the Chinese high-tech sector; the American scientist—collaborating with a high-profile Chinese scientist—became a "China expert". These reputational gains had generated other tangible benefits. For example, the two had attracted likeminded scientists and students to inquire about their tissue engineering research. Some of these interested parties later joined their research and provided useful advice and research assistance.

4.4. Dimmed prisms: trust barriers

Nevertheless, not all partnerships produce desirable results. In fact, whether a partnership could be formed in the first place depends on the perception and position of a particular scientist.

Generally speaking, whether in the U.S. or China, my interviewees who were younger and had a lower status recognized the prestige value of working with "big names"—famous scientists and/or those who work in prestigious universities. With regard to US-China collaboration specifically, my interviewees in the U.S. recognized prestigious institutes in China, but few intended to seek prestige by working with someone in China. My Chinese interviewees recognized prestigious institutes in the U.S., but they did not necessarily know how they could build a productive relationship with foreign scientists.

In short, there existed "two-way trust barriers". For example, the young chemistry professor that I mentioned in the previous section expressed strong reservations over international collaboration. Although he kept frequent contacts with his overseas friends to learn about the latest development in his field, he was very cautious about China's dependence on Western countries in science and technology in the long run. Instead of acquiring legitimacy directly through coauthored papers, he preferred finding out what was considered legitimate to do in his field. From international conferences, journal papers and informal contacts, he could identify the leading scientists in foreign countries. He would only establish contacts with these leading scientists selectively—either because of his own preference or the potential collaborator's unwillingness. With these "good contacts", he was willing to spend time for more in-depth exchanges and "real collaboration". Doing so allowed him to avoid committing in collaborative research that he was not fully interested in.

In some occasions, he even viewed foreign scientists as "opponents". For him, it was important to be aware of what these "opponents" were currently working on because, in his own words, "knowing your opponents will lead you to lose never." He reasoned further: "We didn't pay attention to [opponents] in the past, [but now] our internet technology has improved". With new ICT, he was able to "know his opponent". Also, he was very reluctant to publish his own research on the web: "Why don't we do a homepage? For prestigious Chinese scientists, if a project can win the Nobel Prize, or produce international shining stars, then you wouldn't mind if people pay attention on you. Other situations are better hidden. Because that [strategy of hiding] is to our advantage. Don't totally expose yourself. [Foreign scientists] don't totally understand what I think."

Some of my American interviewees expressed similar skepticisms about collaboration with scientists from China and other less developed countries. Only the more experienced American scientists knew where they could find capable Chinese scientists to collaborate.

4.5. Networks as sponges? Learning by networking

As mentioned, networks provide not only resources and prestige but also ongoing relationships for Chinese science actors. In particular, as indicated by my interviewees, resource or prestige benefits from international networks often require time investment and continuous learning to materialize. In this sense, networks might be better utilized as a learning platform, so that network benefits accrue to science actors gradually (Beckman and Haunschild, 2002). Treating networks as a sponge through which beneficial effects infiltrate to the science actors may also address the problems of clogged pipes and dimmed prisms.

This is possible because networks as sponges provide relatively stable structures of relations that enable organizational actors to store useful knowledge and routines (Gulati, 1999). Stable relational structures not only enable organizational actors to test, verify and improve their procedural knowledge but also increase trust among network partners. In contrast, networks as pipes only make knowledge—whether declarative or procedural—available (Cohen and Bacdayan, 1994). In this sense, networks as sponges seem particularly important for process-oriented innovations; whereas networks as pipes and prisms may be essential to technical innovation only (Benner and Tushman, 2002). My findings in this research do not address the differences between process-oriented and technical innovations directly. Yet, this will be an intriguing direction for further studies.

To put network-based learning in perspective, the experience of an academic Chinese scientist was illustrative. He identified a commercial opportunity from his academic research. Yet, the technical constraints in his home university would not allow him to pursue the commercialization path, which required mass production, patenting, advertising, and other operational tasks. Thus, he became eager to attract an industrial partner and obtain industrial funding. While he did not know how to solicit business interests in the first place, he turned to his network ties in business, trying to learn things by doing.

At first, he was unclear how patents could protect his real economic interests other than the abstract concept of intellectual property, so he continued to consult his Japanese friends. Over time, he learned about the strategy of "writing a basket of patents", and the languages in a patent document had economic as well as symbolic consequences. He acquired this knowledge gradually through working with his Japanese colleagues for years. As he told me, the more important thing to do for a high-tech science such as nanomedicine was being strategic and entrepreneurial, rather than achieving technical sophistication.

International networks also increased understanding of business interests, and facilitate articulation and practice adjustment. These enabled the science actor to exploit the results of basic science, and turned them into applied products (Ahuja, 2000). An important action item in the translation process was about differentiating needs of business enterprises in different sizes, locations, and other organizational factors (Fujimura, 1996). The more well-connected scientists I interviewed had repeated exchanges with enterprises. Consequently, they had developed an acute business sense over time.

In this respect, some enabling factors facilitated building collaborative networks with industry. For example, taking advantage of institutional agreement between one's home university and enterprises was an important one. If there was no pre-existing institutional agreement, alumni could provide useful starting points for forging one. Also, more senior scientists sometimes took advantages of their own reputation and influence in the scientific fields, and turned them into "networking capitals". Enterprises and universities from both local China and foreign countries might recognize these influential scientists, and might be willing to set up a formal relationship with the Chinese institutes through the influential scientists.

Overseas experience was another significant capital for networking. It enabled my interviewees to form reasonable expectations when collaborating with international industrial collaborators. And even less prestigious institutes had scientists with overseas experience. One of my interviewees from a less prestigious institute in Shanghai compared the kind of pressures upon receiving funding from Chinese and overseas sources: "Collaborative activities within China and with overseas researchers give you different levels of pressure. Within China, you have a lot of pressure regarding deadlines and tangible results. . . . However, there is more freedom when you collaborate with overseas researchers." His own overseas experience enabled him to identify overseas collaborators.

Existing ties did not guarantee that the academic scientist could find an immediate solution. Yet, network ties enabled the scientist to gather information from different sources and develop a solution incrementally. The problems of clogged pipes and dimmed prisms might be handled through continuous learning. As mentioned, alumni networks produce a channel of learning by doing. Based on my interviewees, alumni networks often provided the starting point for an industrial partnership. Importantly, alumni shared the identity of the university. They had a kind of "natural bond" with scientists from their Alma mater, and were more committed to forming a partnership with these scientists. In particular, science graduates from prestigious universities such as Peking University, Tsinghua (in Beijing) and Fudan and Shanghai Jiaotong University (in Shanghai) were typically very proud of their home university. When their current company sought an academic partner, they would first refer their home university and helped defend the choice.

4.6. Exploration and exploitation

Many of my interviewees—in both the U.S. and China—recognized the benefits of exploitation and exploration made possible by international collaborative research (March, 1991). This is quite different from the more traditional way of doing science—within boundaries of single disciplines—according to my interviewees. On the other hand, the collaborative process might take more time for the interdisciplinary team to learn from each other, and become familiar with each other's "language" (Nonaka, 1994).

In particular, nanotechnology has been regarded as "inherently multidisciplinary" (Roco, 2007). There are many definitions of nanotechnology, but most scientists agree that nanotechnology research is concerned with matters in the scale of 1–100 nanometers (nm). The diameter of a human hair is about 50,000 nm, and 1 nm is smaller than a DNA molecule. It is believed that the ability to manipulate physical and chemical matters and phenomena in the nanoscale can lead to a large number of applied technologies, and that multidisciplinary collaboration is necessary for synthesizing different knowledge to build new products with nanotechnology (Roco, 2007).

A chemistry professor from a less prestigious university in Shanghai emphasized the importance of continuous learning from other disciplines: "I did physical chemistry, but I now study nucleotides. That means I need to learn about cells and biology. I didn't know the technology regarding how to grow cells." This scientist got his PhD from a Japanese university. He continued to collaborate extensively with researchers from Japan and Hong Kong, and found continuous learning to be very beneficial.

In this regard, network partners in unequal power relations may engage in learning-by-doing in different forms (Contu and Willmott, 2003; Cumbers et al., 2003; Spencer-Oatey, 1997). Although both strong and weaker partners may utilize networks for exploitation and exploration in high-tech science, my data seem to suggest a more specific tendency. That is, the network partner of a higher status—with more knowledge and reputational resources—tended to utilize the lower-status network partner for exploring new R&D and intellectual possibilities. In contrast, the network partner of a lower status tended to utilize the higher-status network partner for exploiting existing R&D and intellectual possibilities. In other words, the higher status partner values the learning-by-doing benefits of networks mostly for exploration; whereas the lower status partner focuses on exploitation (Irwin and Klenow, 1994). For example, my American scientist interviewees sought to learn from their Chinese networks how their research products can enter into the Chinese market. On the other hand, my Chinese interviewee sought to learn from the American experience how their existing research could be exploited and further improved.

Yet, lower-status partner may need more effort to develop a partnership than their higher-status counterpart. This was the case for more than half of my Chinese interviewees. These Chinese scientists sought to partner with a large foreign enterprise to obtain research funding and equipment support. For these purposes, they saw a need to understand the foreign R&D culture. One of my interviewees commented on the importance of rapid technology transfer for multinational enterprises: "In the current society, efficiency is emphasized. [You want] an immediate transfer to applications . . . Think about this GMR's hard disk, [which] has a magnetic head. Its magnetic effects were discovered in 1988, and IBM used it in the 90s. Now many companies have made [the procedures of technology transfer] systematic. So you see new scientific advancement, and it will become technology immediately. The time [for technology transfer] is very short. . . . Economic development is very important."

This scientist was a chemistry professor from a prestigious university in Shanghai. He knew that once a big multinational company such as IBM started developing a certain product, other companies would follow and/or refine the technology within a short time frame. From the enterprise's viewpoint, the academic partner must respond quickly in the R&D process. The scientist told me that he kept an open mind about differences between himself and his international network partners. He was willing to absorb these differences over time by way of continuous learning.

5. Discussions

This research emphasizes that network benefits in science-making are conditional on some enabling conditions and situational factors. More specifically, it shows that the process of science-making has more variations than intuition suggests. The same connecting mechanism—networks—may or may not benefit science actors, depending on how science actors can utilize the

Table 3
Proposed framework of evaluating network costs and benefits in science-making.

Metaphors	Benefits	Costs	Evaluative metrics
Pipes	Amount of resources acquired	Communication and traveling expenses	Benefits-to-costs ratio$_{(resources)}$
Prisms	Level of reputation acquired	Loss of status due to partner's misbehavior(s)	Benefits-to-costs ratio$_{(reputation)}$
Sponges	Degree of learning-by-doing made possible	Time and adjustment difficulties	$\frac{\text{Benefits-to-costs ratio}_{(\text{resource or reputation})}}{\text{Time}(2-1)}$

mechanism strategically to serve particular purposes. Using the metaphor of sponge, I emphasized that networks produce learning-by-doing opportunities. In this sense, networks may increase—rather than depend on—the absorptive capacity of organizational actors (Cohen and Levinthal, 1990). For example, an organization may seek advice from its network partners when facing new knowledge and difficult-to-solve problem(s). The network partner may provide "hands-on" opportunities for the focal organization to try out how the newly acquired knowledge can be exploited to solve R&D and other organizational problem(s). This finding opens an excellent opportunity for further research.

I apply the metaphor of sponge to highlight the indeterminate nature of network benefits among Chinese science actors who were pursuing an emerging high-tech science. For these science actors—as is the case for other organizational settings—networks could be clogged, and/or dimmed. Science actors who value long-term relationships, learning and mutual adjustment were more apt to repair clogged and dimmed networks. It does not mean that networks as sponges are problem-free, but this perspective motivates a more nuanced view of network benefits for science-making in the least.

Third, while network has been conceptualized as a form of capital in recent years (Luk et al., 2008), the utilization of this capital has seldom been formally evaluated in the form of cost-benefit analysis. Based on the findings of this research, it seems quite important to estimate time and financial costs associated with building, maintaining and utilizing collaborative and knowledge networks precisely (Farrell and Klemperer, 2007). Advanced evaluation techniques such as DEA might be employed for this purpose (Van de Ven et al., 2011; Leung and Pasupathy, 2011). Table 3 proposed a scheme of evaluating costs and benefits of networks in the process of science-making.

In this framework, the costs and benefits of networks in science-making may be evaluated with reference to each of the three metaphors discussed in this paper: pipes, prisms, and sponges. In terms of pipes, the emphasis is the amount of resources that are provided by network ties, relative to the communication and traveling expenses for acquiring these resources; in terms of prisms, the emphasis is the degree of reputation that can be acquired from network ties, relative to the potential loss of one's own status; and in terms of sponges, the emphasis is the benefits-to-costs ratios of resources or reputation, relative to the time that is spent for continuous learning in the network(s).

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