# THE ROLE OF TRANSNATIONAL CORPORATIONS IN THE CHINESE SCIENCE AND TECHNOLOGY NETWORK

Stefan Hennemann

With 2 figures, 4 tables and 1 appendix
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**Summary**: Cooperation in knowledge creation processes in China is becoming increasingly diverse. Transnational corporations (TNCs) play a crucial role in innovation and the dissemination of new ideas. They are sought-after cooperation partners for an entire set of other actors (e.g., domestic firms and universities), as they are capable of bringing in the most recent knowledge from abroad. However, it is assumed that they rarely work with domestic public research organisations or universities. Following comprehensive reforms of the science and technology system (S&T) in China and strategic changes in the global TNC organisation, public institutions are more likely to serve as potential cooperation partners in creating new knowledge not only for Chinese companies, but also for TNCs. Therefore, a new variety of exchange processes can be expected, with TNCs occupying a prominent position in the knowledge creation system in China. This paper will analyse the network topology and the position of international firms for the creation of research-oriented knowledge in China's S&T-system. Co-authored publications serve as a proxy indicator for cooperation and knowledge exchange. Between 2003 and 2007, more than 6,000 articles were co-authored with employees of companies in China. These data have been used to create a network that will be analysed using state-of-the-art network science methods. This analysis thus offers a unique insight into the role of TNCs for the Chinese scientific knowledge network.

**Zusammenfassung**: Kooperationen in der Wissensproduktion sind in China zunehmend diversifiziert. Transnationale Unternehmen (TNCs) sind im Zusammenhang mit Innovationsprozessen von großer Bedeutung für die Verbreitung neuer Ideen und Sie sind gleichzeitig begehrte Partner für andere Akteure in Innovationssystemen (z. B. chinesische Unternehmen und Universitäten), weil sie potenziell einen Zugang zu internationalem Wissen bieten. In der Regel kooperieren TNCs nur selten mit öffentlichen Forschungseinrichtungen oder Universitäten in Entwicklungs- und Schwellenländern, aber diese Haltung ändert sich zunehmend. Nach umfassenden Reformen des chinesischen Wissenschafts- und Technologiesystems (S&T) und mit strategischen Veränderungen in der internen Organisation von Forschungs- und Entwicklungsprozessen in den TNC-Netzwerken entstehen vorteilhafte Bedingungen für die Zusammenarbeit zwischen TNCs und öffentlichen Forschungsakteuren. Aus diesem komplexen Geflecht von Austauschbeziehungen entstehen neue Strukturen im chinesischen S&T-System, in dem TNCs zukünftig noch zentraler für die originäre Wissensproduktion sein werden. Dieser Beitrag analysiert die Netzwerktopologie und die Position internationaler Unternehmen im forschungsorientierten S&T-System Chinas. Koautorenschaften wissenschaftlicher Publikationen dienen dabei als Proxyindikator für Kooperationen und den damit verbundenen Wissensaustausch. Zwischen 2003 und 2007 wurden mehr als 6.000 Artikel in Zusammenarbeit zwischen chinesischen Akteuren und internationalen Unternehmen publiziert. Die bibliometrischen Informationen wurden verwendet, um ein Netzwerk zu erzeugen, das mit aktuellen netzwerkwissenschaftlichen Methoden analysiert wird. Damit bietet dieser Beitrag eine einmalige Einsicht in die Rolle transnationaler Unternehmen im chinesischen Wissenschafts- und Technologiesystem.

**Keywords**: Transnational corporations, public research, collaboration-networks, network science, China

## 1 Introduction

Developing countries need their industry base to be linked to the local as well as to the global science and technology (S&T) system in order to make full use of their local development potential and to facilitate technological upgrading (Metcalfe and Ramlogan 2008). China is especially eager to move its capacity towards local innovation and promotes industrial development with a multi-faceted technology policy that includes research, science, and development (Hennemann and Kroll 2008; Fan and Watanabe 2006; Wu 2007). With respect to the overall importance of foreign direct investment (FDI) in China, global-local interaction is crucial in outward-oriented sectors of the economy, because upgrading seems to be most effective in these industries (Iammarino et al. 2008).

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At the same time, technological globalization and strongly linked global networks are becoming more prevalent beyond production chains (Archibugi and Michie 1997). Moreover, the public research sector is well aware of its role in the increasingly relevant science-based industries (Slaughter and Leslie 1997; Frenken et al. 2010). There is initial empirical evidence that suggests that the interaction between transnational corporations (TNCs) and the public research system in China has been increasing in recent years (Motohashi 2008; Li 2010).

Due to changes in international expansion and organisation strategies in TNCs, regional headquarters in particular have been rearranged and consolidated. Home-base augmenting strategies, through which TNCs' own technological advantages are sought to be combined with strong target markets (Le Bas and Sierra 2002, 593), are not only affecting marketing and production management. Most recently, they have also been enabling a strategic coupling of the TNCs' global R&D networks with the local science systems of the target markets. China is in an excellent position to attract crucial functions of TNCs because of its unique combination of market-related development (i.e., increasing demand for high-tech products) and a strong science base (Kümmerle 1999; Chen and Kenney 2007).

Theoretically, global-local networking can be understood as a multi-layered system that includes different actors on different spatial scales (Coe and Bunnell 2003). In such a system, knowledge is exchanged to enhance the capabilities of the locally embedded actors. Knowledge is absorbed, recombined and passed forward through a complex set of exchange relations that make up the special value of networks (Huggins 2010).

Important domestic actors in dynamic emerging economies are quickly integrated into these networks, because they offer complementary assets (e.g., market knowledge) to the established network participants. The function of mediating hubs in these emerging local networks is carried out by gatekeeping focal companies or public research organisations, since they possess the comprehensive reciprocal understanding (i.e., absorptive capacity and resources) needed to exchange knowledge and mediate between global and local sources (Kauffeld-Monz and Fritsch 2010; Chen 2009; Wu 2007).

The analysis of these evolving knowledge networks is currently approached in two different ways. One branch of research focuses on the evaluation of knowledge transmission and on spillovers (cf., for example, Frenken et al. 2010). A second research stream is concerned with the assessment of structural features of (scientific) knowledge networks (cf., for example, Wagner and Leydesdorff 2005). While the former uses patent or publication *citation* data to analyse the dynamics of knowledge dissemination, the latter builds networks from *co-authorships* of publication or patent data to evaluate structural properties of the underlying systems. Both methods and indicators have advantages and drawbacks that are discussed in detail in Griliches (1990) for patent data and in Laudel (2002) for scientific publication data. The most severe obstacle when using patent data is its indication quality, specifically in China, and due to the immaturity of the science system, most dynamic analyses will fail if structural properties are unknown. Therefore, co-authorship data from scientific publications is the least problematic indicator in this context (cf. Wang et al 2005).

The main research gap in this context can be identified as the lack of combination of theoretical concepts and empirical evidence, especially with respect to China. So far, the overall structure of the integration of TNCs into the domestic science *networks* of developing countries is poorly understood, although innovation system studies based on secondary statistics are common (cf., for example, Dobson and Safarian 2008). Even primary empirical research that deals with R&D collaboration processes and innovation is not suited for identifying systemic structures (cf., for example, Liefner and Hennemann 2008).

This article contributes to the reduction of this gap by introducing empirical evidence regarding the interface between TNCs and the science system in China from the perspective of a complex system. This will help to assess the involvement of TNCs in Chinese S&T networks and show the strategic behaviour of TNCs compared to domestic companies in using complementary assets from public research systems. Hence, this approach aims to deliver answers at the macro-level (i.e., the spatial system) and at the meso-level (network relations), but leaves out the micro-level of the organisational routines (cf. Boschma and Frenken 2006, 294).

The rest of this paper is organised as follows: The brief review of empirical trends and the proposed theoretical framework in section 2 help to clarify recent reforms in China and changes in the organisation of TNC networks. A statistical overview of the development of evolving R&D activities of TNCs in China is connected to this explanation. Section 3 discusses the indicators used, the data collection and the proposed methods. Section

4 presents the visual and numerical results of the network analysis. Section 5 discusses the results and provides concluding remarks as well as recommendations for the future direction of research.

## 2 Empirical trends and theoretical framework

### 2.1 Structural changes in the national innovation system of China

With increasingly complex process and product developments, the distinction between industry (IND) and public research organisations as well as higher education institutions (PROHEI) is becoming blurred and is consequently affecting the mode of knowledge production in general. "Universities are the central producers of technoscience" (Slaughter and Leslie 1997), forming science-based industries (e.g., bio-technology, microelectronics). *Pre-competitive research*, i.e., research directly related to a company's success at the enterprise level, and particularly *strategic research*, i.e., broadly targeted research without immediate commercial use, are becoming increasingly important in many of these industries in China (Wu 2007).

In this regard, the tendency in rapidly developing countries to integrate into global networks can also be seen outside typical production and assembly networks in low-technology industries.

Incentives for the involvement in more highly valued business activities are numerous for both private and public research agents. Whereas industry profits from the access to human resources, country-specific knowledge and the use of equipment, public agents stand to gain financial freedom, new intellectual incentives from "real world" problems and the chance to place graduates in appealing international businesses (cf. Hennemann 2006). This trend inevitably leads to a reciprocal convergence of IND and PROHEI. The recent reforms in relevant parts of the Chinese innovation system (i.e., industrial sector, public research system and higher education system) have fuelled these advances towards each other (Hennemann and Kroll 2008).

However, the technological capabilities of many domestic firms are still limited even in terms of simple technology absorption. They concentrate on low-tech products, serving the basic needs of the large markets outside the coastal metropolises such as Shanghai and Beijing. The more sophisticated manufacturers produce for the world market, but with limited local content or value added and without significant local linkages (Lemoine and Ünal-Kesenci 2004, 840), regardless of all the structural changes evident. However, this is about to change.

### 2.2 Changes in global TNC strategies

TNCs have faced difficulties in fully exploiting the potential of global innovation and R&D networks (von Zedtwitz et al. 2004), but recent strategic shifts can be seen as trying to compensate for these difficulties. The intensifying relationship between TNCs and PROHEI is one important part of these changes in the internal and external organisation of TNCs. The spatial distribution of internal R&D and learning is becoming increasingly removed from the pure command and control networks (Gerybadze and Reger 1999) that used to make up "globally networked enterprises." (Auerswald and Branscomb 2008)

This is a remarkable shift from "monolithic approaches" in R&D towards highly flexible regional activities, and is directly related to stronger competitive forces in globalised markets (Lehrer and Asakawa 1999). Global intellectual property management as well as country-specific innovation demands support these decentralisation processes (Slaughter and Leslie 1997). Consequently, selected regional headquarters are forming *centres of excellence* (CoE)/*global knowledge centres* in order to optimize worldwide communication and knowledge exchange with local academic and non-academic communities (Hameri 1996; Gassmann and von Zedtwitz 1999; Gerybadze and Reger 1999; Meyer-Krahmer and Reger 1999; Fang et al. 2002; Asakawa and Lehrer 2003).

The regional management of R&D in CoE is becoming more common in large developing markets in order to adjust to local specifics, to scout for trends, and to enable TNCs to react quickly to changes in market demand and technology. Efficiency motives and the exploitation of cheap labour successively yields competence-seeking that is based on local linkage creation (Santangelo 2009; Blanc and Sierra 1999; Fai 2005). For CoE-related activity in emerging economies, the tendency of TNCs to collaborate with PROHEIs is greater than their collaboration with local industrial bases (Gassmann and Han 2004, 427).

Additionally, due to specific market strategy factors and the socio-political organisation in China, lobbying is an important factor for the activity of

TNCs in local S&T networks. The establishment of regional R&D headquarters enables TNCs to approach key network actors and institutions (Low and Johnston 2008).

### 2.3 Current activities of TNCs in China

The organisational changes in TNCs are already affecting their activities in China's high-tech industries. Until recently, foreign knowledge was brought in through R&D that had been conducted elsewhere. Today, however, the S&T activity of large and medium sized TNCs in China is increasing in relation to that of all large and medium sized enterprises (LME). Table 1 shows the total number of LMEs, the share of foreign-funded companies and the S&T-activities. The compound annual growth rate (CGAR) of the TNC share of all LMEs was 10.0% between 2001 and 2006. The general activity of foreign companies has, therefore, substantially increased.

The number of LMEs having R&D activities or their own laboratories and institutes has also increased, both generally and in particular for TNCs (cf. table 1). However, the empirical evidence for the quality of R&D activities especially, but also for quantity, is mixed and subject to ongoing controversies. In the past, the establishment of local R&D centres in TNCs was linked to Chinese policies and government intervention, but in recent years, there has been some indication that the R&D activity of TNCs is becoming increasingly pronounced due to growing competition for strategic R&D alliances with PROHEI (cf. Li 2010; Sun 2010).

With increasingly localised R&D, the total export volume in all high-tech industries (according to the official Chinese classification) showed a strong annual increase of 31.8 % from 1995 to 2006. The total sales revenues from these exports rose even faster at an annual rate of 42.2 %. Currently, joint ventures produce 85 % of these revenues, while the share of state-controlled companies is continuously decreasing, indicating that the profit-making businesses are mainly those that involve foreign expertise and local R&D capacity (cf. Tab. 2).

In terms of regional activity in China, TNCs are rather concentrated in large economic centres in coastal provinces, utilizing the physical and non-physical infrastructure advantages there (Chen and Kenney 2007). Usually, Beijing is seen as the knowledge centre, whereas historically, Shanghai is a favoured location for international high-tech business activities. This basic pattern has been revealed by recent innovation studies (Liefner et al. 2006). Other areas in China, such as the Pearl River Delta between Hong Kong and Guangzhou, are attempting to upgrade their exceptionally strong FDI-driven industries, but with mixed success (Meyer et al. 2009).

Most direct investments originate from a small number of countries. One-third of the total cumulative FDI volume between 2003 and 2007 was brought into mainland China via Hong Kong. The USA (5.3%) is the second most important investing country, as much of the transfer is carried out via the Virgin Islands (15.8% of the FDI) and the Cayman Islands (3.0%). The same holds true for the United Kingdom. Adjacent Asian economies, such as South Korea (7.5%), Japan (8.1%), Singapore (4.3%) and Taiwan (4.0%), follow in terms of volume. Germany, the Netherlands and France are of minor importance compared to the United Kingdom, but still generate a significant amount of FDI in China (own calculations based on China Statistical Yearbook 2004, 2005, 2006, 2007, 2008).

**Tab. 1: Large and medium sized enterprises and their science and technology activities**

| | 2001 | | | 2005 | | | 2006 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | all LME | FFE | % of total | all LME | FFE | % of total | all LME | FFE | % of total | CAGR |
| **total no.** | 22,904 | 2,665 | 11.6 | 28,567 | 5,031 | 17.6 | 32,647 | 6,128 | 18.8 | 10.0 |
| **no., having S&T Institutions** | 6,000 | 376 | 6.3 | 6,775 | 743 | 11.0 | 7,579 | 944 | 12.5 | 14.7 |
| **% of total** | 26.6 | 14.1 | | 23.7 | 14.8 | | 32.2 | 15.4 | | |
| **no., having S&T Activities** | 10,461 | 909 | 8.7 | 11,060 | 1.602 | 14.5 | 12,068 | 1,849 | 15.3 | 12.0 |
| **% of total** | 45.7 | 31.1 | | 38.7 | 31.8 | | 37.0 | 30.2 | | |

**CAGR - Compound Annual Growth Rate for the Foreign-Funded Enterprise shares between 2001 and 2006**
**FFE – Foreign Funded Enterprises**
**LME – Large and Medium Sized Enterprises**
**(Source: China Statistical Yearbook on Science and Technology 2002, 2005, 2006, 2007, own calculations)**

**Tab. 2: Export volume (a) and export sales revenues from new products (b) in high-technology industries**

| | | 1995 (bn. Yuan) | 2000 (bn. Yuan) | 2006 (bn. Yuan) | CAGR 1995/ 2006 | CAGR 1995/ 2000 | CAGR 2000/ 2006 |
|---|---|---|---|---|---|---|---|
| a) | total export volume | 112.5 | 338.8 | 2,347.6 | 31.8% | 38.1% | 24.7% |
| b) | total sales revenue from new products | 7.0 | 67.8 | 334.2 | 42.2% | 30.4% | 57.7% |
| | Thereof: joint venture companies | 4.5 | 58.8 | 283.2 | 45.6% | 30.0% | 66.9% |
| | % of total | 65% | 87% | 85% | | | |
| | Thereof: state controlled companies | 1.8 | 6.0 | 25.9 | 27.3% | 27.7% | 26.9% |
| | % of total | 26% | 9% | 8% | | | |

**CAGR - Compound Annual Growth Rate**
**(Source: China Statistics Yearbook on High Technology Industry 2007, own calculations)**

## 2.4 Theoretical framework of TNCs in rapidly growing economies

The internal and external organisation of the R&D networks of TNCs determines the degree of visibility in research networks. The establishment of CoEs and the increasing embeddedness in the local S&T system is sometimes achieved at the expense of a detachment from the internal global network of a TNC. This risk, when taken, constitutes a novel approach to TNC subsidiary evolution (Lehrer and Asakawa 2002). Hence, TNCs that act solely as *local adaptors* will hardly appear in basic research-driven networks, whereas *international adaptors,* and even more so *international creators*, will be highly present in these networks (Nobel and Birkinshaw 1998). International creators have strong internal and external networks of relationships that are capable, on the one hand, of improving the position of foreign companies in emerging markets, while on the other hand also stimulate socio-economic development in the host countries, as TNCs' access to local S&T resources shows potential for integrating developing countries into global technology development activities (Reddy 1997).

In this respect, TNCs not only exert direct influence on knowledge transfer, but also indirect influence through collaboration with strong PROHEI that later pass over their knowledge to local domestic companies (cf. Fig. 1). To realize this potential as additional gatekeepers alongside universities or large domestic firms, TNCs have to be physically present with higher order functions in the target market in order to attach themselves effectively to domestic S&T systems. The knowledge exchange is different to production-related collaboration processes. It involves pre-competitive, yet market-related knowledge, and thus opens new opportunities for regional innovation systems to acquire globally relevant technical knowledge. The higher technological level arising from these knowledge transfer processes between TNCs and the domestic S&T system will not have immediate pay-offs for domestic companies, but will help to shape indigenous innovation capacity in the mid-term.

This view of the additional role of TNCs in technologically upgrading economies such as China marks a shift from the classic notion of the technology licensing global firm and explains the recent activities of TNCs in China.

The structure of the gatekeeping function (i.e., networking position) and the spatial location of TNCs in the Chinese S&T system will be investigat-

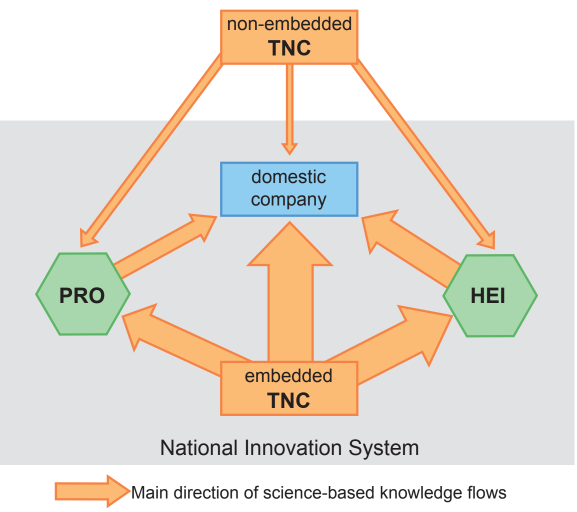


**Fig. 1: Direct and indirect paths of knowledge dissemination from embedded and non-embedded TNCs to domestic Chinese firms**

ed under the guidance of the following four research hypotheses:

H1 The scientific collaboration activity in the knowledge network is spatially concentrated in a small number of coastal centres, which act as regional science network hubs.

H2 The international integration pattern of the knowledge network is congruent to the regional pattern of the main regions of origin for foreign direct investments in high-tech industries.

H3 The network position of TNCs in the Chinese science network is superior, i.e., more central than the network position of domestic companies.

H4 TNCs are integrated into dense parts of the network, where they obtain direct access to many different knowledge pools. TNCs with regional headquarters in China occupy network positions with higher centrality than TNCs from abroad.

These hypotheses will be investigated by analysing a complex network built using co-authorship data.

## 3 Material and methods

### 3.1 Co-authored publications as an indicator for research collaboration

Cooperation in knowledge creation processes between different people or organisations is difficult to track directly. Instead, an indicator is necessary to represent formal and informal idea exchange, as well as for the successful new combination of thoughts. Scientific collaboration is very often represented by co-authorship and publication data. However, although the adequacy of co-authorship data has been fiercely debated in the past (Katz and Martin 1997), many authors are still investigating knowledge production, dissemination, or scientific activity by using bibliographic indicators.

Co-authorships are at the heart of scientific activity. These indicators are also easily available and rather comprehensively collected. They are a record of successful scientific work. Co-authored publications are the outcome of formal and informal knowledge sharing, negotiation and reformulation activity, and they possess a quantifiable dimension as well as information about content. In addition, the measuring procedure does not affect the measured items and offers an inexpensive method of analysing large scale data sets (Lundberg et al. 2006). Nevertheless, it must be acknowledged that bibliographic data only capture a fraction of the overall collaboration activity and constitute only one variable (Katz and Martin 1997). However, with increasingly relevant output of knowledge as proof of success, a large part of the collaboration activity is presumably included (Laudel 2002; Melin 2000).

In this article, the emphasis is on collaboration between TNCs and other research agents in the Chinese innovation system with a special focus on strategic, basic research, rather than on applied and pre-competitive research. The number of papers that have been co-published with companies is large, so it is logical to use this as an indication for collaboration at the interface between private and public research.

This indicator is certainly not comprehensive, since many joint projects between industrial and public research sectors do not result in any publication, with exact numbers remaining unknown. This fact has to be taken into consideration when interpreting the results, as suggested by Lundberg et al. (2006). However, it is not incorrect to assume that most seminal work will be published sooner or later, because scientists are usually required by their employers to publish, resulting in an adequate picture of the TNC activity in the Chinese science network.

### 3.2 Data collection and pre-processing

The data for this analysis was gathered from the ISI Web of Science (http://apps.isiknowledge.com/). The raw dataset included all extended article information for the years 2003 to 2007, but was restricted to all articles that listed a contributor with a Chinese address. These raw data were analysed to identify the individual contributing organisations. After comprehensive data cleaning (e.g., misspellings, incorrect locations, etc.), the contributing organisations were categorised into appropriate groups (TNC, domestic Chinese, PRO, HEI, others). A TNC was identified as being either a company from outside China (=non-Chinese address) or a Chinese affiliation of a foreign company (=registered address in China). All other companies were considered domestic.

These raw data were used to select articles that met the following conditions and to define the network linkages:

- Articles with between *2 and 10 contributors* were included. With a group of more than 10 people, it is questionable as to whether intensive knowledge sharing takes place. Sometimes the contributors of multi-author papers do not even know each other (Laudel 2002).
- At least one of the co-authors had to be affiliated

with either a domestic OR a foreign company.
- The lowest *level of aggregation* is the organisational level rather than the individual author. Therefore, only publications co-authored by at least *two different* organisations were considered. This also avoided many interpretation problems with respect to collaboration within research groups.

### 3.3 Calculation and visualisation

The data were organised in the form of an undirected graph containing nodes that represent the actor groups and edges representing each single act of collaboration (i.e., co-authoring a paper). The edge creation was based on a complete inter-wiring of all co-authoring organisations of a paper. If a paper has three different co-authoring organisations, the edges *a-b*, *a-c*, and *b-c* were created. Since it is possible to have more than one publication between any two organisations, the graph contains multiple edges.

Most networks are not completely connected, but consist of several unconnected components. Usually, the largest of these (sub-)components, i.e., the largest fully connected network that can be identified, is used to perform a network analysis, because algorithms do not work with unconnected networks. In the following analysis, all analytical steps are performed with the largest connected component, which contains almost 72% of all 6,700 nodes (=individual organisations) in the network.

The numerical calculations were made with algorithms provided by the package *NetworkX* (http://networkx.lanl.gov/contents.html) for the programming language *python*. A brief overview and definition of the scores is provided in the appendix.

Generally, large-scale networks with more than one thousand nodes are difficult to visualise, especially when the node location is determined by its location in space, rather than the position in the network. The world map of Chinese company-driven scientific collaboration networks (cf. Fig. 2) attempts to avoid this visualisation problem by smart filtering and the bending of edges, allowing for the physical distance between the connected nodes.

The visualisation was realised using the spatial extensions of the mySQL database server (http://dev.mysql.com/doc/refman/5.0/en/spatial-extensions.html) and further calculations in python to create a scalable vector graphics (SVG, http://www.w3.org/Graphics/SVG/) file. The geo-coding was done using the Google-Maps API class GClientGeocoder (http://code.google.com/intl/de/apis/maps/documentation/reference.html\#GClientGeocoder).

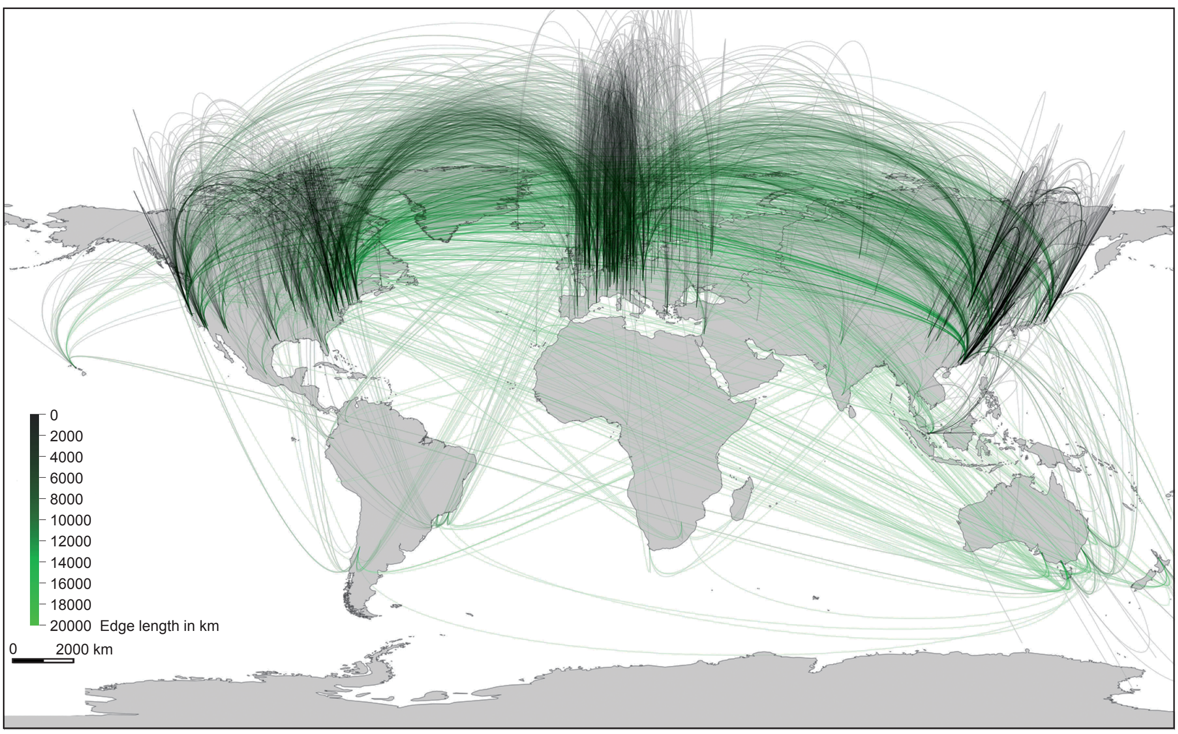


**Fig. 2: World map of collaborating organisations in the Chinese-centred global TNC research network**

## 4 Results

### 4.1 General features of the network and data

After applying the restrictive conditions (see above), there were still more than 6,000 articles remaining for the given period of time. This number corresponds to the general share of companies contributing to scientific articles that have been registered in the ISI Web of Knowledge Database. A company contribution share of around 5 to 20%, depending on the scientific field, is common for scientific publications (cf. Carayannis and Alexander 2006).

In total, 4,800 individual organisations are part of the largest connected component. Almost 50% of these nodes represent companies, of which 57% (=1,541) are located outside China (=1,354) or represent an affiliation of a TNC in China (=187). Altogether, companies from 49 countries are involved, with 80% coming from a mere 7 countries (USA, Japan, Germany, Canada, UK, Singapore, South Korea) (cf. Tab. 3).

**Tab. 3: Origin of the companies and non-companies in the network**

| Originating Country | Companies [%] | Non-Companies [%] |
|---|---|---|
| **PR China** | 51.1 | 30.2 |
| **USA** | 22.3 | 17.9 |
| **Japan** | 8.9 | 8.7 |
| **Germany** | 3.2 | 4.3 |
| **Canada** | 2.4 | 2.4 |
| **United Kingdom** | 2.0 | 3.9 |
| **Singapore** | 1.3 | 0.9 |
| **South Korea** | 1.0 | 2.7 |
| **Australia** | 0.9 | 2.7 |
| **Switzerland** | 0.8 | 0.7 |
| **The Netherlands** | 0.8 | 1.6 |
| **Taiwan** | 0.6 | 2.1 |
| **Russia** | 0.1 | 1.3 |
| **India** | 0.2 | 1.1 |
| **other** | 4.6 | 19.5 |
| **sum** | 100.0 | 100.0 |
| **total no. of countries** | 49 | 79 |

**Remark: the PR China includes Hong Kong; 14.0% of all companies in China were identified as TNC**

### 4.2 Visual representation of the Chinese-centred global TNC research network

The visualisation in figure 2 clearly demonstrates that most of the activity is regional (strong solid and dark edges) and few connections span larger distances (blurred and transparent light coloured edges). The relatively low occurrence of broad activity in China with few but heavily active regions is striking. This can be derived from the dark lean spikes in the coastal areas and from the sharply contoured green-shaded pipes to Europe and North America. In contrast to this strong concentration, the European intra-regional connectivity is much more widely dispersed and displayed in blurred shading.

The interaction with Japanese actors is also quite intense. About one-fifth of all TNCs are located in Japan, but the involvement of other research organisations is lower than for pure scientific networks, for which Japan holds a very important neighbouring position. The USA is overwhelmingly prevalent with respect to TNC activity. Around 45% of all TNCs are from the USA. The United Kingdom, Germany and Canada follow with about 6% each. Interestingly, the USA and Singapore are the only countries that have a higher share of companies in the network than that of non-company organisations (cf. Tab. 3). This overall pattern does not completely reflect the FDI inflow shares, and therefore constitutes additional valuable information concerning the activity of TNCs in China.

Besides these activities, only a small number of other global spots can be identified. Generally, the collaboration activity with South America, Australasia and Africa is significantly lower than the collaboration with the leading global science centres.

In China, only a few organisations are capable of cooperation with first-class research units abroad. This leads to a spatial concentration pattern. More than one-third of all Chinese TNC affiliations in the network are located in Shanghai, almost 30% in Beijing, 14% in Hong Kong and around 4% each in Jiangsu, Guangdong, Tianjin, and Zhejiang. The spatial distribution of domestic firms is less concentrated, but still displays major activity in coastal areas. This activity pattern is mirrored by the public research activity that constitutes the backbone of the S&T network of China.

This visual inspection, accompanied by relative frequency distribution patterns, both global and domestic, provides tentative support for hypotheses H1 and H2.

The general visual overview will be deconstructed in the following section in order to clarify the role and position of domestic and foreign companies in the scientific network.

## 4.3 Network positioning of TNCs and local companies

Generally, the network relevance of companies is low compared to that of public research agents. The backbone of the scientific network is dominated by a small number of universities (e.g., Tsinghua University, Shanghai Jiaotong University, and Fudan University) and large CAS institutes in Beijing and Shanghai. However, this unsurprising result is not part of the focus of this analysis. With the classification of companies into three categories, non-embedded TNCs from abroad, embedded TNCs in China, and domestic Chinese companies, the network centrality scores thus allow mean comparisons and significance tests based on t-statistics and analysis of variance. This will help to assess the positioning in the network according to the remaining hypotheses H3 and H4.

Firstly on average, TNCs are significantly more active in contributing to the scientific community than domestic Chinese firms. Table 4 shows that the TNC affiliations in China are involved in 9.0 collaborations, as compared to 5.3 collaborations of Chinese companies (indicator: no. of edges). Furthermore, the degree reveals that the directly neighbouring nodes are more diversified (i.e., a higher number of different partners) for TNCs from abroad than for TNCs in China. This means that the latter collaborate more intensively with repeated contacts. Consequently, TNCs are significantly more central in the network (indicator: closeness), which is especially true for TNCs located abroad.

Secondly, the number of triangles and the related measure of clustering shows a significantly stronger local network embedding for TNCs, i.e., a higher cross-connectivity of adjacent nodes. Interestingly, the clustering is higher for TNCs from abroad than for TNCs in China, but, at the same time, the number of triangles is dramatically higher for TNC affiliations in China. This may be related to a higher propensity for unique and heterogeneous partners for the TNC affiliations in China. As a result, the circulating knowledge may be much more comprehensive, although the number of different partners is higher for TNCs abroad.

Thirdly, this linking behaviour leads to very important strategic positions in networks, where sparsely connected parts can be spanned. The betweenness as well as the bridge and the structural hole measure indicate this highly relevant position of TNCs in China, not only compared to domestic firms, but also compared to TNCs that are located abroad.

**Tab. 4: Mean comparisons based on an analysis of variance (ANOVA) using *Games-Howell* post-hoc multicomparisons (pairwise)**

| | | Mean | sig. |
|---|---|---|---|
| **degree** | TNC abroad | 0.0007 | 0.000 |
| | CN firms | 0.0004 | |
| | TNC in CN | 0.0006 | |
| **closeness** | TNC abroad | 0.2695 | 0.000 |
| | CN firms | 0.2637 | |
| | TNC in CN | 0.2674 | |
| **betweenness** | TNC abroad | 0.0001 | |
| | CN firms | 0.0001 | |
| | TNC in CN | 0.0003 | |
| **bridge** | TNC abroad | 0.0788 | |
| | CN firms | 0.0599 | |
| | TNC in CN | 0.1056 | |
| **structural hole** | TNC abroad | 0.0004 | |
| | CN firms | 0.0003 | |
| | TNC in CN | 0.0009 | |
| **no. of triangles** | TNC abroad | 38 | 0.000 |
| | CN firms | 16 | |
| | TNC in CN | 475 | |
| **no. of edges** | TNC abroad | 7.6 | 0.000 |
| | CN firms | 5.3 | |
| | TNC in CN | 9.0 | |
| **clustering** | TNC abroad | 0.4843 | 0.000 |
| | CN firms | 0.2749 | 0.046 |
| | TNC in CN | 0.3447 | |

**The *Games-Howell* test was used due to inhomogeneous variances among the three groups. This procedure is suggested by Janssen and Laatz (2007, 369) for pairwise comparisons with unequal variances and/or non-Gaussian distributions.**

**TNCs abroad, n=1,354**

**Chinese firms, n=1,150**

**TNCs in China, n=187**

In summary, TNCs are, in general, more active in connecting to the S&T base in China than domestic firms, at least in the most sophisticated form of producing scientific, strategic knowledge. They are significantly more central in the network, which enables them to exploit knowledge creation better. They are more efficiently connected and, in most cases, able to broker between sub-networks. TNCs that are located abroad are, however, less strategically embedded. The TNC affiliations in China, by contrast, occupy areas with high knowledge throughput and a higher integration into domestic S&T know-how.

These findings from the network analysis confirm hypotheses H3 and H4.

## 5 Discussion and conclusion

The local presence of TNCs in the form of regional headquarters with R&D activities contributes to the strategic integration of these companies into the S&T system in China. International cooperation between TNCs from abroad and Chinese organisations (e.g., domestic companies, universities, and public research organisations) is less fruitful in terms of knowledge acquisition potential. This has been recognised by TNCs and has led to a change in the global organisation of company networks since the 1990s.

Altogether, the local as well as the global network presence of TNCs is of greater relevance than the positions of Chinese domestic companies. This has direct impact on the ability to mediate between sub-networks, i.e., parts of local dense areas that are comprised of actors, which deal with similar content. TNCs with large internal knowledge bases may be best suited to occupying these strategic positions.

At a first glance, these results are not surprising, since TNCs possess a greater capacity to evaluate, integrate and disseminate knowledge than domestic firms in developing countries. However, it is commonly acknowledged that collaboration activity is not extended to local PROHEI, as TNCs bring in and rely first and foremost on their own knowledge. Clearly, this is still the most important source of knowledge for the local operations of TNCs in China. The empirical findings presented here reflect the theoretical considerations rather well. Among other factors, either strategic positioning (e.g., future access to human resources, graduates) or content-driven motivations seem to be the most plausible possibilities for the activity of TNCs in local S&T networks. The former is a clear response to the severe shortage of human capital in rapid catch-up development processes. The latter motivation may be driven by the strong competition of emerging markets. TNCs are willing to secure their own position and combine their firm-specific comparative advantages with location-specific scientific advantages that may help to extend their position in science-based industries. Some of the underlying scientific fields may offer unique advantages in China over other locations (e.g., relaxed legislation in stem cell research).

The clarity of the strategic advantage of local R&D centres and TNCs located in China over those TNCs that are connected from abroad is surprising. Today, a sharp increase in serious research and sophisticated technological upgrading can be seen in the large metropolitan areas in coastal China. TNCs are integrating into these local communities and are better off pursuing R&D activities in China. The lobbyism argument brought up in the literature on the subject provides a strong explanation for this result.

The spatial concentration in coastal provinces and the metropolitan areas is connected with the rapid improvement of the science system in these regions. Results from the Beijing - Shanghai Innovation Survey 2003 showed a different involvement of public research organisations and universities. Until recently, most domestic companies tried to compensate for the lack of international partners with collaboration partners from academia (Liefner and Hennemann 2008). TNCs were just beginning to go beyond simple production and home-base augmenting strategies. This situation is obviously changing slightly. Former labour-cost-based export strategies are being replaced by higher valued activities, and the collaboration represented by co-authorships may be just the tip of the iceberg. It can be assumed that smaller joint projects are even more common.

With the increasing integration of TNCs into local Chinese knowledge networks, there is a good chance that the collaboration with public research agents will improve knowledge dissemination into domestic companies. The integration of the S&T backbone into international S&T networks through mediating TNCs is likely to enhance upgrading capabilities in the Chinese innovation system.

This article has shown that the increase in activity following the comprehensive reforms in the Chinese S&T system on the one hand, and changes in global TNC strategies with respect to R&D on the other, can be traced by analysing scientific papers. Companies in general are heavily active in scientific knowledge production, as they regularly co-publish cutting-edge material in international journals. This is not unique to the prominent knowledge-intensive regions in post-industrialised economies, but is also present in rapidly developing economies with strong science bases such as China. TNCs in China make substantial use of the local science base to enhance their own knowledge pools.

However, the quantitative method presented here cannot qualify the directions of knowledge flows, i.e., it remains unclear as to which actor is benefiting to what extent from participating in alliances between TNCs and domestic organisations of the Chinese S&T system. This lack of information on qualitative aspects of network structures must be addressed in further research projects by adequate means (e.g., in a mixed method approach of in-depth interview series that investigate the factors behind the network structures identified). Further research may also be directed towards the dynamics of TNCs in science networks in developing countries. The official Chinese statistics have shown an increasing prominence of local R&D centres in general and of TNCs in particular. At the moment, dynamic network analysis seems awkward, since a significant increase in publication activity in China, as well as the involvement of companies in scientific papers in general, is a relatively recent phenomenon. Another valuable amendment would be the decomposition of the data into homogeneous scientific fields. This may reveal structural differences in the networks for different technologies and topics. Last, but not least, other suitable indicators, such as domestic and international patents, should be processed with comparable methods to reflect the market-related interface between TNCs and public research organisations in the Chinese S&T system.

**Appendix: Definitions of the network scores and measurements**

| Measurement | Definition |
|---|---|
| **Degree** | D. is the number of direct neighbours of a node and a measurement of the local (in the network sense) centrality; normalised by the number of all nodes |
| **Closeness** | C. is the reciprocal value of the average shortest path length to all other nodes in a network and a measurement of the global (in the network sense) centrality of a node |
| **Betweenness** | B. of a node is the number of all shortest paths from all nodes to all nodes that go through the node and a measurement of flows; normalised by the number of all possible shortest paths |
| **Bridge** | Br. is the ratio of the betweenness and the degree and a measurement of the efficiency and power of a node; high flows and a small number of adjacent nodes yield a strategic and non-redundant network position |
| **Structural Hole** | SH. is the ratio of betweenness and clustering and a variant of the bridge measure; high flows in areas of low clustering yield a non-redundant network position |
| **Triangle** | T. is the number of fully connected triples of nodes the node is involved in; a higher value signals a higher activity |
| **Edges** | E. is the number of direct connections a node possesses to other nodes |
| **Clustering** | C. is the number of potential triangles for a node that are in fact triangles; C. is a measurement of the local density (in the network sense) |

**Notes: details about calculations and the measurements can be found, for example, in Newman (2003) or Albert and Barabási (2002). Source: own compilation**

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## Author

Dr. Stefan Hennemann
Department of Geography
Economic Geography
Justus-Liebig University Giessen
Senckenbergstr. 1
35390 Giessen
Germany
stefan.hennemann@geogr.uni-giessen.de