

KNOWLEDGE AND INNOVATION FLOWS IN THE CHINESE TECH SECTOR

A Thesis

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by

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ABSTRACT

In this thesis, I use patents filed at the United States Patent and Trademark Office as a proxy for company's technology innovation ability. I apply graph theory, economic network analysis to look at the historic development of the Chinese high-tech industry over time. My research finds that before 1997, under the support of the Chinese government, the state-owned energy company Sinopec was the only company that filed patents in America. In the early 2000s, the computer manufacturing company Lenovo filed the most patents in America. Since 2006, the telecommunications industry has overtaken the computer manufacturing industry as the most innovative industry in China. Although 14 out of Huawei's top 20 competitors are American firms, when it comes to 5G technology, Huawei has no US rivals. Recently, the rise of patents filed by the Chinese e-commerce giants indicates China starts to have an edge in e-commerce technology innovation.

BIOGRAPHICAL SKETCH

Changlun (also called "Aaron" when he dines at Cornell Dining everyday) originally comes from a tiny village in a tropical island– Hainan island, China. Changlun has been, is, and will always be a proud Cornellian. Before coming to Cornell in 2019, Changlun was a banker in Shenzhen, Hong Kong, and Shanghai, chronologically. Changlun first came to the United States in 2013, with a full scholarship from his then-employer to study at University of Illinois at Urbana-Champaign for nine months. Changlun has long been dreaming of pursuing a Ph.D. at one of the most prestigious schools in America, which was the reason Changlun quit his lucrative job (if you ask him) and came back to academia. As a Chinese diaspora, Changlun has considered Cornell as his sweet home. It is worth mentioning that Changlun has never left Ithaca since he came here in August, 2019, partly due to his heavy workload and his strong work ethics, or maybe because of the Covid-19 pandemic that has swept across America since March 2020. Changlun will be doing his Ph.D. in Applied Economics and Management at Cornell since August, 2021. In the future, Changlun would like to be a great, well, at least a fine economist.

In his free time, Changlun is a movie buff. Believe it or not, he is especially into the Marvel ones. He also likes rock-climbing, hiking, traveling, etc., if he has the time. He likes proof-based math, but not calculation-based ones. Although a self-proclaimed cosmopolitan, outside of China, the only country that he has been to is America. He likes great food from all over the world, e.g. deep dish pizza in Chicago, pizza in Little Italy in New York city, roast goose in Hong Kong.

Professionally, Changlun holds a BA in Engineering Management from the Central University of Finance and Economics in Beijing. He also holds a MA in Economics (specialty: Finance) from Peking University. He passed all the CFA exams in the shortest time period possible and was a CFA Charterholder from 2016 to 2019.

This thesis is dedicated to Changlun's Muses, from whom he derives inspiration.

It is also dedicated to all the beautiful things in life, without which life has no
meaning.

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Second, Changlun would also like to thank his family, friends, whoever has inspired him and whoever has been kind to him. Changlun would like to thank the Cornell community for being supportive, especially so as this thesis was written during the Covid-19 pandemic.

Last but not least, Changlun would like to thank his own perseverance and grit. It is what makes this journey so wonderful and what makes life worth living.

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CHAPTER 1

INTRODUCTION

As the economic facing-off, the tugging of trade dispute between the United States and China escalates, the two biggest countries have been trading blame now and often for technology issues. Chinese tech giants like ZTE, Huawei, Tencent and Alibaba, especially, are most frequently involved in the trade spat.

In March 2017, after a five-year probe since 2012, ZTE pleaded guilty to have violated U.S. sanctions on Iran and to have obstructed justice, and was fined \$892 million. In April 2018, the U.S. Commerce Department banned American firms from selling software and components to ZTE for its violating the terms of the 2017 deal. The ban would have decimated ZTE if it was not reversed three months later by the Trump administration. ZTE has been a political football in the broadening trade war between China and America during this period (Strumpf (2018)).

It did not take long before Huawei to replace ZTE as the central figure in the trade fight between two economic superpowers. Meng Wanzhou, Huawei's CFO, who is also the daughter of the company's founder, was arrested in Canada in December 2018 at the request of the United States for Huawei's allegedly evading U.S. sanctions on Iran and Meng Wanzhou's role in the violation. In response, very soon China took a reciprocal action to detain two Canadians in China. America has long accused Huawei of theft of intellectual property, of its aid in developing surveillance technology and new weapon systems. Besides, the Trump

administration warned its allies that Huawei gears could be used by the Chinese government to spy globally. In May 2020, the Trump administration banned non-U.S. semiconductor manufacturing firms from shipping products made using U.S. software and technology to Huawei without first securing a permit from the U.S. government (Davis and Ferek (2020)). In August 2020, the U.S. government doubled down, issuing new rules to prohibit foreign firms from selling any chips made using U.S. technology to Huawei without a special license. This time the new rules covered even widely available, off-the-shelf chips made by foreign firms, placing severe new limits on Huawei's ability to source components and parts. The new rules negated Huawei's efforts to find workarounds to the U.S. restrictions placed in May (Strumpf and Ferek (2020)).

On January 5, 2021, then outgoing U.S. president Trump signed an executive order banning transactions with eight Chinese software applications, including Alibaba's Alipay, Tencent's QQ Wallet and Wechat Pay, etc. It is not my intention to document the nuts and bolts of all the technology-related issues that witness the unwavering dispute between the United States and China.

As these examples illustrate, technology sector has become the hottest battleground for China and the US. Although United States has long been and is arguably the world technology leader, China has been catching up. To examine the Chinese technology clout, it is of great importance to investigate the Chinese technology industry. In this thesis, I use patents filed at the United States Patent and Trademark Office (the "USPTO") as a proxy for company's technol-

ogy innovation ability. I apply graph theory, economic network analysis to look at the historic development of the Chinese high-tech industry over time. My research finds that before 1997, under the support of the Chinese government, the state-owned energy company Sinopec was the only company that filed patents in America. In the early 2000s, the computer manufacturing company Lenovo filed the most patents in America. Since 2006, the telecommunications industry has overtaken the computer manufacturing industry as the most innovative industry in China. Although 14 out of Huawei's top 20 competitors are American firms, when it comes to 5G technology, Huawei has no US rivals. Recently, the rise of patents filed by the Chinese e-commerce giants indicates China starts to have an edge in e-commerce technology innovation.

CHAPTER 2
DESCRIPTIVE STATISTICS

2.1 Patent Definition

The USPTO's definition for patent is "A patent for an invention is the grant of a property right to the inventor, issued by the United States Patent and Trademark Office". Under to 35 U.S.C. § 101, Whoever invents or discovers any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof, may obtain a patent therefor, subject to the conditions and requirements of this title. Besides, "Novelty" and "Non-obviousness" are two conditions for obtaining a patent. "Novelty" means the patent must be new as defined in 35 U.S.C. § 102. To violate the "Novelty" requirement, the subject matter to be patented must be exactly identical to the prior arts (Quinn (2017)). "Non-obviousness" refers to the requirement that the invention to be patented must be sufficiently different from the prior arts that it is considered to be non-obvious to a person having ordinary skill in the area of the technology related to subject matter to be patented(USPTO (2015)).

2.2 Databases

For my purposes, I use Google Patent Database, and the Global Corporate Patent Dataset (“UVA data”) that was put together in mid-2017 by the University of Virginia. The UVA data contains 3,090,554 granular patents filed by public companies at the USPTO that were later approved by the USPTO from 1901 to mid-2017, as well as 83,253,916 backward citation pairs, and 83,774,547 forward citation pairs.

The difference between backward citations and forward citations lies in which patent is being cited. Backward citations are citations that a specific patent cites when filing, or citations that are added to a specific patent by the patent examiners. Patents that are cited are called “prior arts”. Patent examiners are of great significance in patents’ backward citations. Alcacer and Gittelman (2006) estimate that two-thirds of backward citations an average patent cites are inserted by the examiners; besides, 40% of patents’ backward citations are all assigned by the examiners. Thompson (2006) finds inventor citations only account of 41% of the time, while examiner citations account for 54% of the time. Forward citations are the citations that a specific patent receives after it is filed, from other patents. Forward citations are generally interpreted as a measure of social spillovers, in the sense that social value minus private value Kline et al. (2019).

The UVA granular data only includes patents that are approved by the USPTO and granted to public companies. Each patent is linked to a public company by Standard & Poor’s Compustat database identifier “gvkey”. Figure 2.1 shows the

total number of patents from 1901 to 2017 in the UVA granular data. The number of patents filed at the USPTO have been growing significantly since mid-1970s. For the backward citation pairs and forward citation pairs data, the data not only include patents that are granted to public firms, but also include private firms' patents.

For all patent datasets, we face the truncation problem. It is not an exception to the UVA data. This explains why the number of patents in the UVA granular data decreases significantly starting from 2012. According to the USPTO, the traditional total pendency is 22.9 month in December 2020. The traditional total dependency is the average number of months from the patent application filing date to the date the application has reached final disposition (e.g., issued as a patent or abandoned), which is called a "disposal". This pendency includes the time periods awaiting action by the USPTO, as well as any time awaiting reply from an applicant (USPTO (2021)). However, this number can be significantly underestimated and deceptively low. It is not uncommon for companies to "revise and resubmit", divide, or "continue in part" their patent filings, which all entail redesignation of a patent filing date. Although the USPTO documents the history of the patent filing process, the filing date in most databases uses the last filing date. Therefore, the total pendency is shorter than it really is. If the first patent filing date was used, the total pendency would be much longer than the one disclosed by the USPTO (Lerner and Seru (2017)). To fix the truncation problem, I restrict my analysis to applications filed on or before 31 December 2013 to limit the impact of censoring. I drop the UVA granular data starting from 1 January 2014, which

includes 148,479 observation (4.8 % of the total observation). Although I drop the granular data starting from January 1, 2014, I keep all the forward/backward citation pairs in the data. This implies that for a patent filing before 2013, if it receives forward citation in 2014 to 2017, I can still track and use this forward citation pair in my analysis.

As the UVA granular data only covers public firms, to account for the patents filed by Chinese private firms, I also use Google Patents, which covers the whole collection of granted and published patent applications from the USPTO that date back to as early as 1790 and those from the European Patent office since 1978 (Cornell University Library 2021).

2.3 Sample Selection

I define Chinese firms as those firms whose headquarters are based in Mainland China. First, I start with the Compustat Global database to get Chinese public firms. For the Compustat Global data downloaded on October 15, 2020, there are 49,504 unique companies, of which 4,668 list a Chinese headquarters (LOC="CHN"). To filter those companies that are most likely to have filed patents in the United States, I rank the firms with a Chinese headquarters by overall sales in each year from 1987 (the first available year in Compustat Global) to 2013 (I choose 2013 to be the last year in the sample to deal with the aforementioned truncation problem). To make sure that the sample includes top companies from

each year, and to make sure that I am not introducing bias in the selection process, I pick top 50 companies for each year. Most of the companies tend to remain top companies from year to year, but there are some new entrants and exits. When I stack top 50 companies from each year and remove duplicates, I get 215 Chinese public companies. Out of 2015 Chinese companies, 9 of them filed for the patents in the US system - USPTO. In total, the sample includes 4,366 patents filed by these 9 companies at the USPTO from 1989 to 2013. Table 2.1 lists the 9 companies.

Table 2.1: Nine Chinese Public Companies Identified from Compustat

| gvkey | Company Name | No. |
|--------------|---|------------|
| 133870 | Petrochina Co Ltd | 1 |
| 140756 | China Petroleum & Chemical Corp Sinopec | 2 |
| 20530 | Alibaba Group Holding Ltd | 3 |
| 242058 | Boe Technology Group Co Ltd | 4 |
| 243858 | Zte Corp | 5 |
| 270615 | Tencent Holdings LTD | 6 |
| 253759 | Byd Company Ltd | 7 |
| 146352 | Aluminum Corp of China Ltd | 8 |
| 260654 | Weichai Power Co Ltd | 9 |

The number of patents filed by these 9 Chinese public firms at the USPTO (figure 2.2) has been growing significantly since 2000 (Figure 2.2). It is worth noting that the total number of patents filed in 2011 and 2012 is not necessarily smaller

than the number of patents filed in 2010 or 2013. Since the USPTO only publishes patents that are granted, it could be that a larger part of the patents filed by these Chinese public firms in 2011 and 2012 has not been approved by the USPTO or that the USPTO has approved less patents filed in 2011 and 2012 than patents filed in 2013 as of mid-2017.

Next, I supplement the list of publicly traded companies with companies that are not. It is worth mentioning that the public companies that I get from the Compustat Global database by setting LOC = "CHN" do not include all the Chinese public firms whose headquarters are in Mainland China, as some public firms might choose to list their headquarters in the city that their stock is issued or in the tax havens. For example, Lenovo Group Limited (SEHK: 992) is a Chinese Public firm listed at The Stock Exchange of Hong Kong. Its legal domicile is in Hong Kong, while its actual headquarters is in Beijing. By using the aforementioned algorithm, I cannot get Lenovo since its LOC value in the Compustat Global database is "HKG", rather than "CHN". However, although ZTE is also listed in Hong Kong, its LOC value in the Compustat is "CHN". Therefore, I am extremely careful not to conclude that the Chinese public companies filtered in this way are complete.

To address the issue of left-out public firms, together with the intention of getting private firms that have filed patents in the United States, I use the "China Top 500 Private Enterprises Lists" that are issued by the All-China Federation of Industry and Commerce (henceforth "the ACFIC", a governmental agency) from

2015 to 2020 (All-China Federation of Industry and Commerce (2018a), All-China Federation of Industry and Commerce (2018b), All-China Federation of Industry and Commerce (2018c), All-China Federation of Industry and Commerce (2018d), All-China Federation of Industry and Commerce (2019), All-China Federation of Industry and Commerce (2020)). Each year, the ACFIC issues a “China Top 500 Private Enterprises list”. It is not clear how the companies are chosen and by what criteria they are ranked in the list. For the list of 2020, the threshold for the top 500 private enterprises stood at \$2.96 billion in revenue; their total revenue reached \$4.42 trillion in 2019; their total assets stood at \$5.42 trillion; and their net profits after tax reached \$200 billion. We should pay special attention to the meaning of “Private Enterprises” in the lists. In the context of the socialist market economy that was introduced by then Chinese President Zemin Jiang in 1992, the socialist market economy is composed of the public sector and the private sector, both of which are important parts of the socialist market economy (The Communist Party of China Central Committee (2019)). “Private” and “public” in this context are not about whether the company is publicly listed or not, but about whether the company is wholly or partly owned by the government or not. Therefore, I can find Huawei (a non-publicly listed firm), as well as Lenovo and ZTE (both are companies listed in Hong Kong) in the lists. I also keep the top 50 companies in each year, stack them to get a company list and check whether these companies filed patents before or on 31 December 2013 at the USPTO, by checking their patent data from Google Patent. Although only three companies, i.e., Huawei, Lenovo, and Baidu, are identified by this method, these three companies turn out to be important fo-

cal firms as can be shown in the rest of this paper. Since Lenovo and Baidu are publicly listed firms, I can find their patents from the UVA patent database. At the same time, I find 9,576 Huawei patents that I filed before or on December 31, 2013 and published before mid-2017 in Google Patents. I am extremely careful not to include Huawei patents filed before January 1, 2014 but were approved published after July 1, 2017 so that the Huawei patents from Google Patents are consistent with the UVA database.

Finally, I append the 9,576 patents to the original UVA granular data to get all the Chinese patents filed at the USPTO. To compare the number of U.S. patents with the number of non-U.S. patents, I retrieve the non-U.S. patents from Google Patents Database. From Table 2.2, we can see that the Chinese telecommunications giant Huawei filed the most patents at the USPTO, about five times as much as those filed by the ZTE Corp, the company filed the second most patents at the USPTO. Huawei is also the companies that files the most patents outside of USA. Among the 12 focal companies, PetroChina, BYD, Weichai Power, Aluminum Corp of China, and Baidu file markedly less patents in America; while Huawei, Zte, Boe, and Lenovo, especially Huawei, account for the majority of Chinese patents in the United States.

Table 2.2: U.S. and Non-U.S Patents of Focal Chinese Companies before 2013

| N | Company | U.S. Patents | Non-U.S.Patents |
|----------|---|---------------------|------------------------|
| 1 | Huawei Technologies Co., Ltd. | 9576 | 121077 |
| 2 | Zte Corp | 2196 | 84161 |
| 3 | Boe Technology Group Co Ltd | 1253 | 14781 |
| 4 | Lenovo Group Ltd | 1008 | 14005 |
| 5 | China Petroleum & Chemical Corp Sinopec | 308 | 45659 |
| 6 | Tencent Holdings LTD | 293 | 14784 |
| 7 | Alibaba Group Holding Ltd | 246 | 5901 |
| 8 | Petrochina Co Ltd | 41 | 19718 |
| 9 | Byd Company Ltd | 24 | 15055 |
| 10 | Weichai Power Co Ltd | 3 | 2110 |
| 11 | Aluminum Corp of China Ltd | 2 | 2554 |
| 12 | Baidu Inc | 1 | 3449 |

Figure 2.1: The USPTO Total Patents of Public Firms (1901-2017)

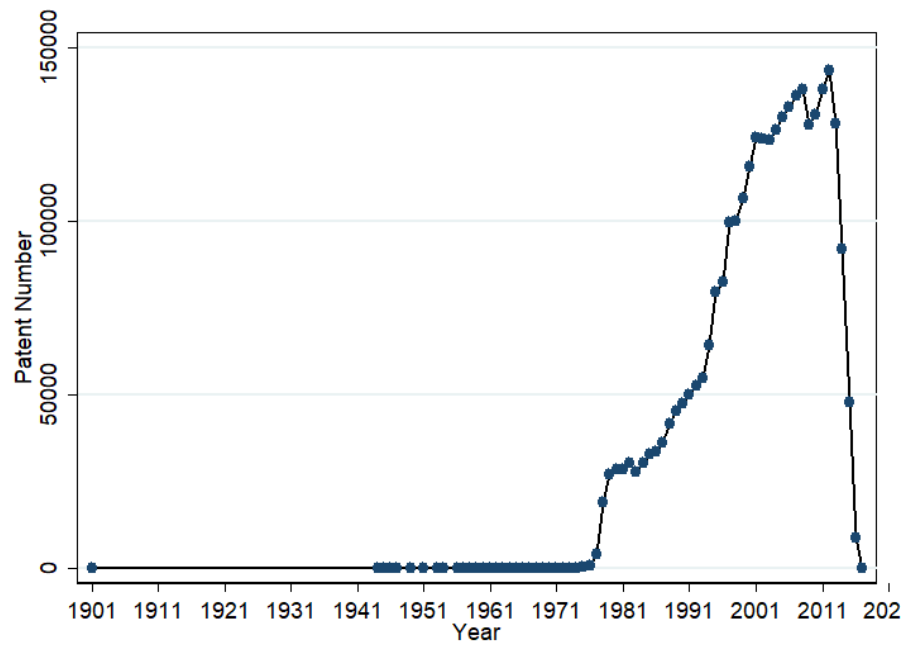
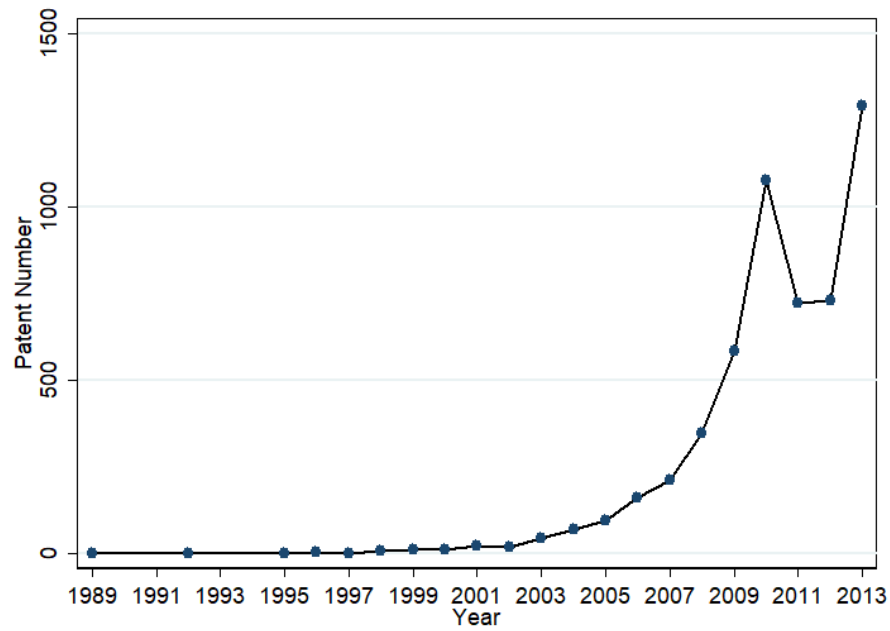


Figure 2.2: The USPTO Chinese Public Firm Patents (1989-2013)

¹The Chinese public firms in this graph are identified by LOC="CHN" in Compustat Global database. As analyzed in this chapter, the numbers in this graph are underestimated



CHAPTER 3

LITERATURE REVIEW

Given the availability of the granular citation data, it is natural to come to the idea of using network analysis to both present and analyze the relationship between different companies. I propose to draw network graph based on the patent data that have been described in the previous section. Specifically, I mainly focus on patent citation in this paper, because patent citation provides us the link between patents (firms) as well as the technological relation between a patent and its “antecedents” and “descendants” (Trajtenberg et al. 1997).

Krugman (1991) once argued: “Knowledge flows... are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes.” However, I argue that part of the flows can be observed and I aim to document them in my network analysis.

Ever since the late 1990s, there are numerous research papers that use network concepts and theory to understand how the innovation system and knowledge is formed and how it spreads. Chen and Hicks (2004) use a method that combines network theory, network graphs, and patent citation analysis to trace knowledge diffusion between science and technology. They use nearly 3 million US patents that are made available by National Bureau of Economic Research (NBER) and find that patent citation networks are scale free, which is indicated by the fact

that the citation degree distribution follows a power law distribution, with an exponent of 2.89. This further implies that citation networks are characterized by hubs (a node with large number of links that significantly exceed the average is called a hub in network science.) through which knowledge flows.

Li et al. (2007) use the citation networks of nanoscale science and engineering (NSE) patents, submitting institution, technology fields, and countries to understand the knowledge transfer process between the two patents/institutions/technology fields/countries. They find wide interactions between the entities, which indicates a largest giant component that includes most of the nodes and edges. They also find that knowledge transfer in the submitting institution citation networks is more efficient than in a random network; the efficiency of knowledge transfer in the country citation networks is close to that in a random network; the citation network at the patent level and the submitting institution level have lower efficiency in knowledge transfer and diffusion. Except the citation network at the technology fields level, the citation network at all the other three level demonstrate a trend to form local clusters, indicating intensive cooperation and knowledge transfer between them. The degree distribution of the citation network at the patent level indicates that only a small number of patents have more citations and play a disproportionately important role in the knowledge diffusion process.

Hung and Wang (2010) use RFID patent data from the USPTO database and characterize the patent citations network as a small world, which indicates a few

important patents might affect the other patents quickly and dominate the development of the technology. They also find the power law distribution of the patent citations network, which indicates relatively few patents have more citations than other patents and these few patents play a critical role in the process of knowledge exchange and diffusion. They also identify patents with high betweenness centrality, i.e., patents play a significant role in the process of knowledge transfer.

Small (1973) first introduced co-citation analysis in bibliometrics. Co-citation in bibliometrics is defined to be the frequency of two documents being cited by other documents. It makes use of the citation relationship among 3 or more documents. Co-citation between two documents happens if at least one document cites them both. Co-citation analysis in bibliometrics assumes that documents that are co-cited are related in one way or another. The more the document pairs are co-cited, the more similar they are. By linking two co-cited documents with other documents with which they are co-cited, researchers can form clusters of documents. Through analysis of such clusters, researcher can identify research frontiers. Bibliographic coupling is another similarity measure besides co-citation. Bibliographic coupling happens when two works cite the same third work in their bibliographies. It is a method introduced by Kessler (1963) and is one of the earliest citation analysis methods for documenting similarity. Bibliographic coupling indicates that there is possibility that two documents treat a related subject matter.

It is not difficult to apply both methods in patent analysis. Mogee and Kolar (1999) identify the major technology fronts of Eli Lilly & Co., by using co-citation

analysis method. They cover 2808 USPTO patents assigned to Eli Lilly from 1975 to 1998. 750 out of 2808 patents clustered and fell into 132 clusters, 74 of which have 3 or more patents. The cluster with the most patent lies in the field that has been or is pursued fiercely by the company. They then examine the Eli Lilly patents relevant to raloxifene and related compounds. They conclude that a company and its competitors can use this method to identify its or its rival's core technology areas and make according decisions as to whether to delve into, (not) follow up on, or abandon a specific filed, etc.

Huang et al. (2003) use USPTO patents of 58 Taiwanese firms, as well as the citations made by these patents to map Taiwan's electronic industry. They use the strength of bibliographic coupling to identify the strength of relation between company pairs. They then use cluster analysis method to identify major sectors of the Taiwan's electronic industry.

Based on 3108 USPTO patents assigned to the Taiwan Semiconductor Manufacturing Company, Wu and Chen (2007) use the co-citation structure in patents to identify core technology capabilities for the Company. They take the age of patents into account when evaluating the citation frequencies to downplay the significance of older patents and to place more weight on younger patents. This method can efficiently and effectively focus on current and potential core technology capabilities, at the same time successfully deal with the truncation problem that is inherent in patent data and patent analysis. They identify 4 core technology capabilities of the company and conclude that the company's core technology

capabilities lie not only in the process of semiconductor manufacturing, but also in the process of production control.

Using the patent data from the Derwent Innovations Index, based on the co-citation data, Wang et al. (2011) calculate the Jaccard similarity coefficient matrix of patent assignees. By ranking the Jaccard coefficient from largest to smallest for 217 Fortune 500 company, they identify the competitor-pairs for these 217 focal companies, via which they draw co-citation networks and hence identify several main technology groups in the Fortune 500 companies and vividly reveal the relationship among the companies and technology groups.

Verspagen (2007) uses a citation network that considers both co-citation and coupling to map the technology trajectories in fuel cells. Verspagen admits that the usefulness of patent citation network in mapping technology trajectories is promising. However, a network of too sparse nodes misses other important information, while a network of too many nodes by no means is clear and easy to interpret. He emphasizes that without qualitative information about the engineering history of the field in question, it will be difficult to make use (sense) of the paths in the network graphs. He recommends the combination of historical approach and citation network methods to understand the technology trajectories in patent knowledge space.

CHAPTER 4

METHODOLOGY

My methodology is mainly composed of three parts. First, I propose to use network graphs to show both the backward and forward citations of Chinese firms. Second, I use patent citation bibliographic coupling Jaccard index to identify closest competitors of the Chinese companies; finally, I visualize the competitor-pairs by network graphs. Third, I compare the technological impact of the competitor-pairs. I aim to present a big picture of the technology landscape concerning the Chinese companies and give a broad but accurate sense of growth of the Chinese companies and the change of the Chinese tech industry over time.

To document and identify the patent citation relationships for the focal Chinese firms and other firms, I aggregate the patent counts and patent citation behavior at the company level, i.e., the nodes in network graphs in this step stand for different firms, rather than patents. This way, patent citation network graphs at the company level not only show both the backward and forward citations of Chinese firms, but they also shed light on the technology flow concerning Chinese firms. Below I explain the core network concepts that are relevant in analysis.

4.1 Patent Citation Network

First, I map the citation relationships into graph theory notation. For the citation network graphs, I use the entity-to-entity directed relationship tables where the

typical (i, j) entry indicates the patent of firm j cites patents of firm i . Thus this relationship indicates the knowledge flow from firm i to firm j . Let $N = 1, 2, \dots, n$ denote the nodes/vertices/players/entities/firms/companies (I use these words interchangeably throughout the paper) in the network. g is real-valued $n \times n$ adjacency matrix, where $g_{ij} = 1$ represents the directed relation from firm i to firm j . g_{ij} indicates a link, tie, or edge between i and j . The thickness of the edges are proportional to the frequencies of the citation relation. The adjacency matrix that indicates which nodes are linked (adjacent) can represent a graph. A patent citation graph/network (N, g) consists a set of nodes $N = 1, 2, \dots, n$ and a real-valued $n \times n$ adjacency matrix g . Next, I look at the global patterns and local patterns in the networks.

Degree is arguably the most fundamental characteristic of a network. The degree of an entity is the total number of edges that involve that entity. It is the cardinality of an entity's neighborhood. Therefore, entity i 's degree in a directed network g is denoted as $d_i(g)$, where $d_i(g) = \#\{j : g_{ij} \neq 0\} = \#N_i(g)$. To normalize degree centrality, I divide by the maximal number of other nodes in the network, i.e., $n - 1$. In this way, I get a normalized degree between 0 and 1. Similarly, (normalized) weighted degree is defined as the total number of weighted links that involve an entity.

I use degree centrality to measure how important a node (node i) is in the network. Degree centrality is defined as the total number of links that involve node i . This definition indicates degree centrality is just its degree. The network

graphs in this step are directed graphs, theoretically I can use weighted indegree and weighted outdegree, i.e., the number of weighted links that point to a specific node i and the number of weighted links that emanate from node i , respectively. To give a broad sense of the importance of the nodes, I believe degree centrality can capture the big picture at this first step. It is straightforward that the average weighted degree measures the overall degree of the whole network. It is used to measure the weighted number of links compared to the number of nodes. I quantify it as:

$$d(g) = \frac{\sum_i d_i(g)}{N}$$

Figure 4.1 shows the average weighted degree for the citation networks each year. The average weighted degree has increased steadily since mid-1990, especially since 2000. Visually, as can be seen in the network graphs in the appendix, the citation networks become denser over time. This implies that China's technology industry has become more outward facing and more embroiled in the world industry.

Besides using degree to measure the global patterns, we can use clustering to measure the local pattern, which is the extent to which one node's connections are connections of each other. In this paper, I am interested in the fraction of the companies that are linked to a specific company are linked with each other. I use average clustering coefficient to check how tightly clustered the patent citation networks are. The individual clustering for an entities i is calculated by:

$$Cl_i(g) = \frac{\#\{j \in g \mid k \neq j, j \in N_i(g), k \in N_i(g)\}}{\#\{jk \mid k \neq j, j \in N_i(g), k \in N_i(g)\}} = \frac{\sum_{j \neq i, k \neq i, k \neq j} g_{ij} g_{ik} g_{jk}}{\sum_{j \neq i, k \neq i, k \neq j} g_{ij} g_{ik}}$$

$$= \frac{\#\{jk \in g \mid k \neq j, j \in N_i(g), k \in N_i(g)\}}{d_i(g)(d_i(g) - 1)}$$

The average clustering coefficient gives an overall indication of clustering in the network. It is the mean value of individual coefficients and is calculated by:

$$Cl(g) = \frac{\sum_i Cl_i(g)}{N}$$

The average clustering coefficient calculated in this way places more weight on the low degree nodes. Figure 4.2 shows the citation network average clustering coefficient each year. Before 2001, the average clustering coefficient is zero. Since 2001, it turned positive and began to trend upward overtime (although some of the years it Int up and down). Overall, both the global pattern and the local pattern indicate that China’s technology linkages with the world has deepened.

Patent citation has been an old warhorse of research in innovation for the following reasons. First, citations, together with content analysis and re-classification, have been used to search for technology families and compare the knowledge base of companies based on their technology portfolios (Pilkington et al. (2002)). Second, the distribution of citations is an important indicator of the “originality” and “generality” of the patent. Patents whose backward citations from a more technologically dispersed array of patents are deemed to have more “originality”, while patents whose forward citations from a broader array of technology class are considered to have more “generality” (Lerner and Seru (2017)). Patents with more “originality” and “generality” are interpreted as having more value in terms of the research being patented. Third, and most important to us,

citations of patents are interpreted as “paper trails” left by patents. These “paper trails” form the knowledge relation between the cited patent and the citing patent (Breschi and Lissoni (2004)), which can be further analyzed using advanced graph theory and network graph. To the best of my knowledge, this paper is the first one use patent citation data to analyze the relationship between Chinese firms and non-Chinese, especially American firms. This analysis serves as a big motion picture of the structure and trend of Chinese patents. However, one disadvantage of my analysis is that: as the UVA granular data only contains patents filed by public companies, even if I can get the patent information for a specific Chinese private company from Google Patent, I cannot get all the information for other non-Chinese firms. Therefore, my analysis only focuses on the relationship between Chinese firms (both public and private) and other public (mainly non-Chinese) firms.

4.2 Patent Bibliographic Coupling Network

As my goal is to identify competitors of Chinese companies based on the citation (including both backward and forward citation) network I do in the previous step, given the availability and ease of dealing with the data, I propose to use patent bibliographic coupling to identify possible competitors, as bibliographic coupling indicates the two coupled companies might treat a related subject matter. Building on the work Wang et al. (2011) has done, I propose a Jaccard coefficient index

(also known as the Jaccard similarity coefficient) that is the patent bibliographic coupling version of theirs. As we know, Jaccard index is defined as the intersection divided by the union. In my approach, I define the intersection as the times two companies cite another company (other companies). Accordingly, I use backward citations of when calculating the intersection and hence the Jaccard index.

$$J_{BC}(i, j) = \frac{coupling(i, j)}{citation(i) + citation(j) - coupling(i, j)}$$

where $J_{BC}(i, j)$ is the Jaccard coefficient of the patents of company i and company j . $coupling(i, j)$ denotes the times that company i and company j cite another company (other companies), $citation(i)$ and $citation(j)$ indicates the backward citations of company i and company j , respectively.

4.3 Forward Citation as a Proxy for Technological Impact

As I have discussed, the analysis of patent citation is largely built upon the previous research in bibliometrics. The use of forward citation as a proxy to examine the technological impact of patents is not an exception. Garfield (1955) first proposed a citation index that “can eliminate the uncritical citations of fraudulent, incomplete, or obsolete data by making it possible for the conscientious scholar to be aware of the criticism of early papers”. Trajtenberg et al. (1997) first used forward citation and backward citation in devising multiple indexes (“F-measures” and “B-measures” in their paper, respectively) to quantify “basicness” and “appropriability” of patents and examine the linkages between these two characteris-

tics of patents. Examining their assumption that universities conduct more basic research than companies, they conclude that the F-measures of “importance” and “generality” reflect the features of the “basicness” of patents. Besides, they use the self-citation data to construct measures of the “appropriability” and find that these measures are much lower for universities than corporations, indicating that these measures could serve as an indicator of the extent to which innovators succeed in reaping the harvest of their own innovation.

Albert et al. (1991) conduct a validation study of forward citations, using 77 silver halide technology patents, ranging from those highly cited, infrequently cited, receiving 0 citation, or receiving 10 or more citations, granted to Eastman Kodak by the USPTO. Twenty researchers/research managers who are experts in the field of silver halide technology are asked to rank the technology impact of these 77 patents. They find a significant association between the highly cited patents and experts’ opinion as to the technological importance of patents. This finding first lays the ground for using forward citation as a proxy for technology impact.

Narin (1995) demonstrates that prominent patents like those appearing in patent office publications as “Hall of Fame” patents, as well as those that have attained the pioneering patents legal status, are highly cited. This further lends credibility to the believe that forward citations serve as a good indicator for technology impact.

Czarnitzki et al. (2011) relate “wacky patents” (“wacky patents” are those selected by an employee of the World Intellectual Property for not involving a high inventive step or only marginally satisfying the “nonobviousness” criterion.) to two control groups of patents to test the usefulness of commonly used patent-based measures to identify “wacky patents”. They find that “wacky patents” have higher originality, generality, and citation lags, however, forward citations serve as a good indicator of technology importance. This finding indicates we should interpret patent-based measures with great care.

In this paper, I attempt to use forward citation as an indicator of technological impact to compare Chinese firms and their competitors, and to decide if the Chinese firms has caught up with the west in terms of innovation and has come to the point that they pose a serious threat to other companies.

Figure 4.1: Citation Network Average weighted Degree

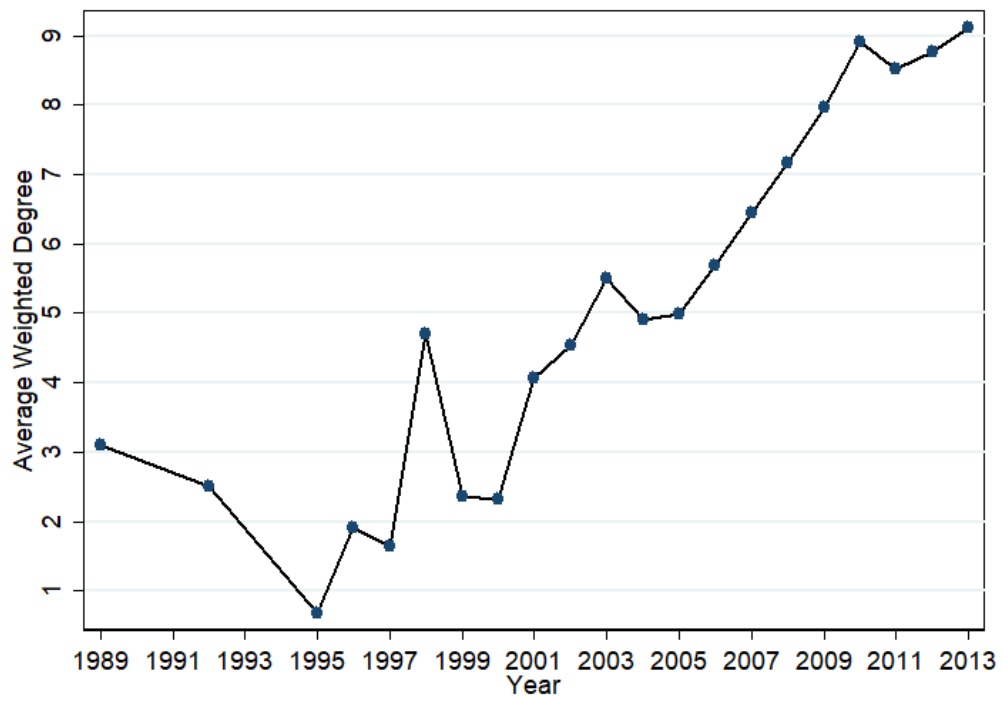
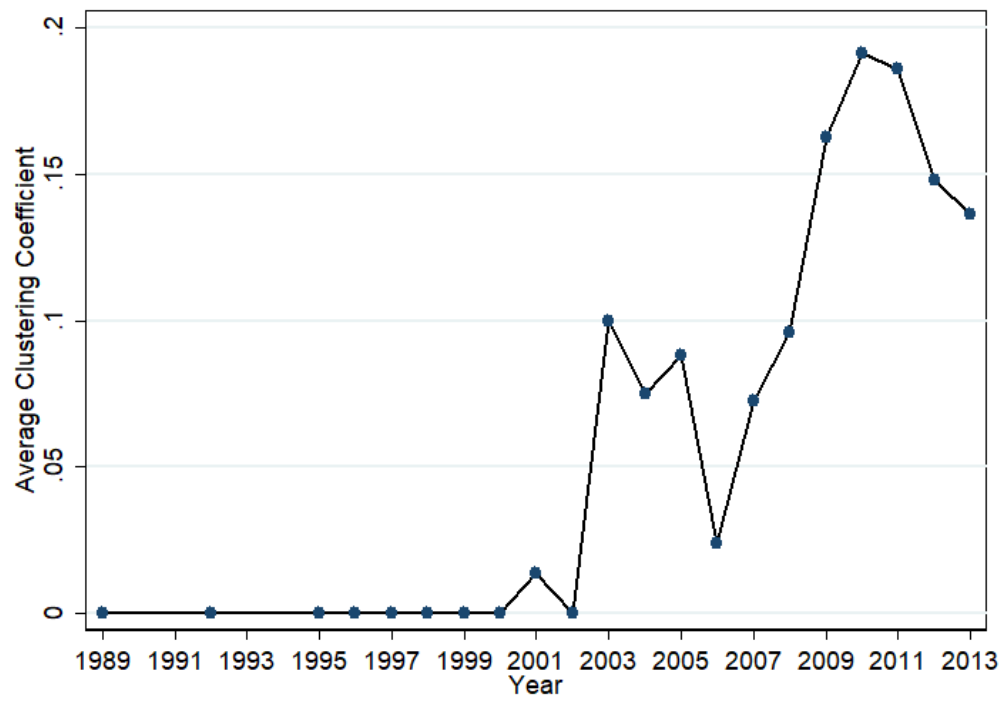


Figure 4.2: Citation Network Average Clustering Coefficient



CHAPTER 5

RESULTS

In this section, I divide my analysis into three periods: 1989-1997, 1998-2006, and 2007-2013. This division is purely based on the evolution of the citation network graphs each year. This division has nothing to do with Beijing's policy, world economics trend or the like. As is shown by the below analysis, this division captures the gist of development and evolution of the Chinese firms as well as its industry. Using the data and method I described in section 4, I draw the patent citation networks as well as the bibliographic coupling networks.

The citation network graphs are directed network graphs with one-headed arrows as the links. The node size is proportional to its weighted degree centrality. The firm with the higher degree weighted centrality has a larger node size. I use two color-blind friendly colors (green and burgundy) in the graphs. The green-color nodes indicate the Chinese companies, while the burgundy-color nodes stand for the non-Chinese firms. The arrow heads connect the citing patents, while the arrow tails connect the cited patents. The arrow heads point to the direction of the knowledge flows in the patents. The color of the link is the same as the color of the cited patents. That is to say, the color of the links indicates the source of the knowledge flow in the citation pairs. To make the graphs readable, I use the top 50% of the backward citation pairs as well as the top 50% of the forward citation pairs in the citation network graphs.

The definitions of nodes and links in the bibliographic network graphs are similar to the ones in the citation network graphs. Nevertheless, the bibliographic network is undirected network. The links has no arrows. Any two nodes at the two ends of a link in the bibliographic networks stands for the two companies that cite patents (a patent) from a third or more common firms. Therefore, I use gray-color links in the bibliographic networks. To filter the competitors that are most related to the Chinese firms, as well as to make the bibliographic network graphs readable, I only use the top 2% pairs (identified by the Jaccard index) for each Chinese firm. The 2% threshold is from my trial-and-error process of drawing the graphs. Like the top 50% cut-off in the citation networks, the 2% threshold is just a number that gives us the most optimal trade-off between "readability" and "being informative". Even so, this top 2% competitors can still give us significant insight into the industry as my analysis unfolds.

5.1 1989–1997 Period

Figure 5.1 is the patent citation network graph for the period from 1989 to 1997. During this period, only one Chinese company–The China National Petrochemical Corporation (the "Sinopec") filed patent at the USPTO, so I group the data in this 9-year period to draw the network graph. Among all the Sinopec's forward citations, Shell cites most patents from Sinopec. Among all the Sinopec's backward citations, Sinopec cites most patents from Mobil. The weighted in-degree

of Sinopec is 27, while the weighted out-degree of Sinopec is 49 in this period. For the company pairs, some of the pairs only have one relation, i.e. only one company cites the other. For example, Sinopec cites Standard Oil once, but not the other way round. P & G cites Sinopec 6 times, not the other way round, either. Actually, if I use all the citation pairs, I find that some of the pairs have two relations, i.e., one company cites the other company and vice versa. For example, in the Shell-Sinopec citation pair, there exist two opposite one-headed arrows connecting them, indicating one company serves as both the backward citation and forward citation of the other. In this period, Shell cites Sinopec 14 times, while Sinopec cites Shell once. In this paper, I use the Global Industry Classification Standard (GICS) developed in 1999 by Standard & Poor's and Morgan Stanley Capital International when discussing and evaluating the industry sectors, to which each Chinese company belongs. The sector for Chinese public firms can be found in the Compustat data, while the sector for private firms is given by us based on the its primary business activity.

Sinopec, which was established in 1983, is one the three largest state-owned oil companies that has been dominating China's Energy industry. The other two companies are the China National Offshore Oil Corporation (founded in 1982, henceforth "CNOOC"), and the the China National Petroleum Corporation (established in 1988, henceforth "CNPC"), respectively. CNOOC, the first oil company in China, was set up partly as a response to western firms' request of a single Chinese interlocutor with the legal authority to sign and execute contracts (Meidan (2016)). The establishment of Sinopec signifies the beginning of the cor-

poratization of China's oil industry downstream. Compared to CNPC, Sinopec is a more downstream oil company, which is also indicated by their names.

In China's ninth Five-Year Plans for 1996 to 2000, China set up a goal of making its petrochemical industry competitive with world-leading oil companies with regard to technology, management, efficiency, and product quality. Beijing set this goal with the objective of establishing the petrochemical industry as one of China's "pillar" industries that will be on par with international standards by year 2000. According to the Plans, this is achieved by introducing advanced technology, improved products, and better management. Sinopec was tasked with policy-making in terms of China's refining and petrochemical industry (Meidan (2016)). Figure 5.1 shows only Sinopec filed patents at the USPTO from 1989 to 1997. By the aforementioned analysis, it is not a surprise that Sinopec was the only oil company in this period filed patents at the USPTO. As can be seen from the appendix, it was not until 2000 did CNPC filed patents at the USPTO. Moreover, Sinopec is the leading company in the energy sector filing patents at USPTO, while CNPC filed significantly less patents than those filed by Sinopec.

In this period, only one the top 2% competitors (Standard Oil) was cited by Sinopec. The other Sinopec's top 2% (12 in total) competitors did not cite Sinopec or were not cited by Sinopec. Figure 5.2 is the bibliographic coupling network for Sinopec and its top 2% competitors filtered by the Jaccard index. We can conclude that during this period, China's energy industry (Sinopec) was not significantly integrated with the its competitors through patent citation behaviors.

Figure 5.1: Patent Citation Network (1989–1997)

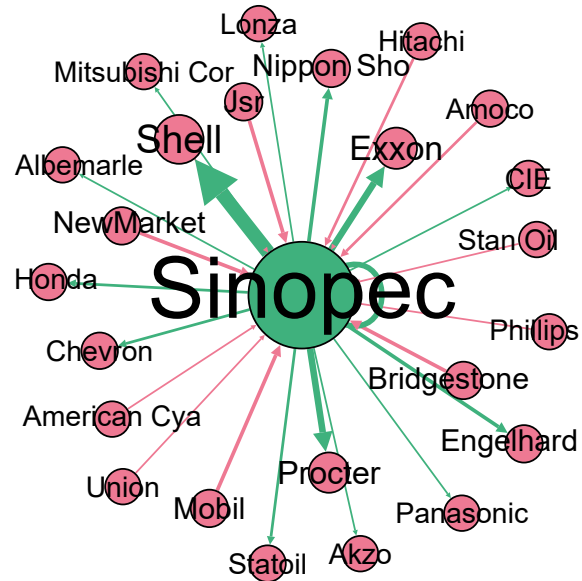
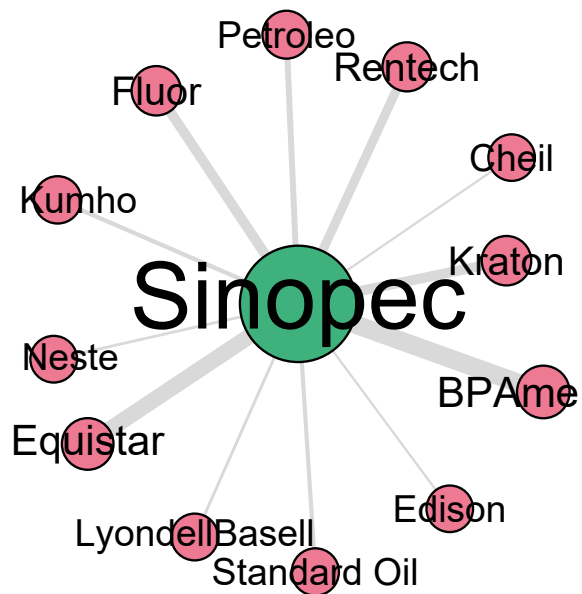


Figure 5.2: Bibliographic Coupling Network (1989-1997)



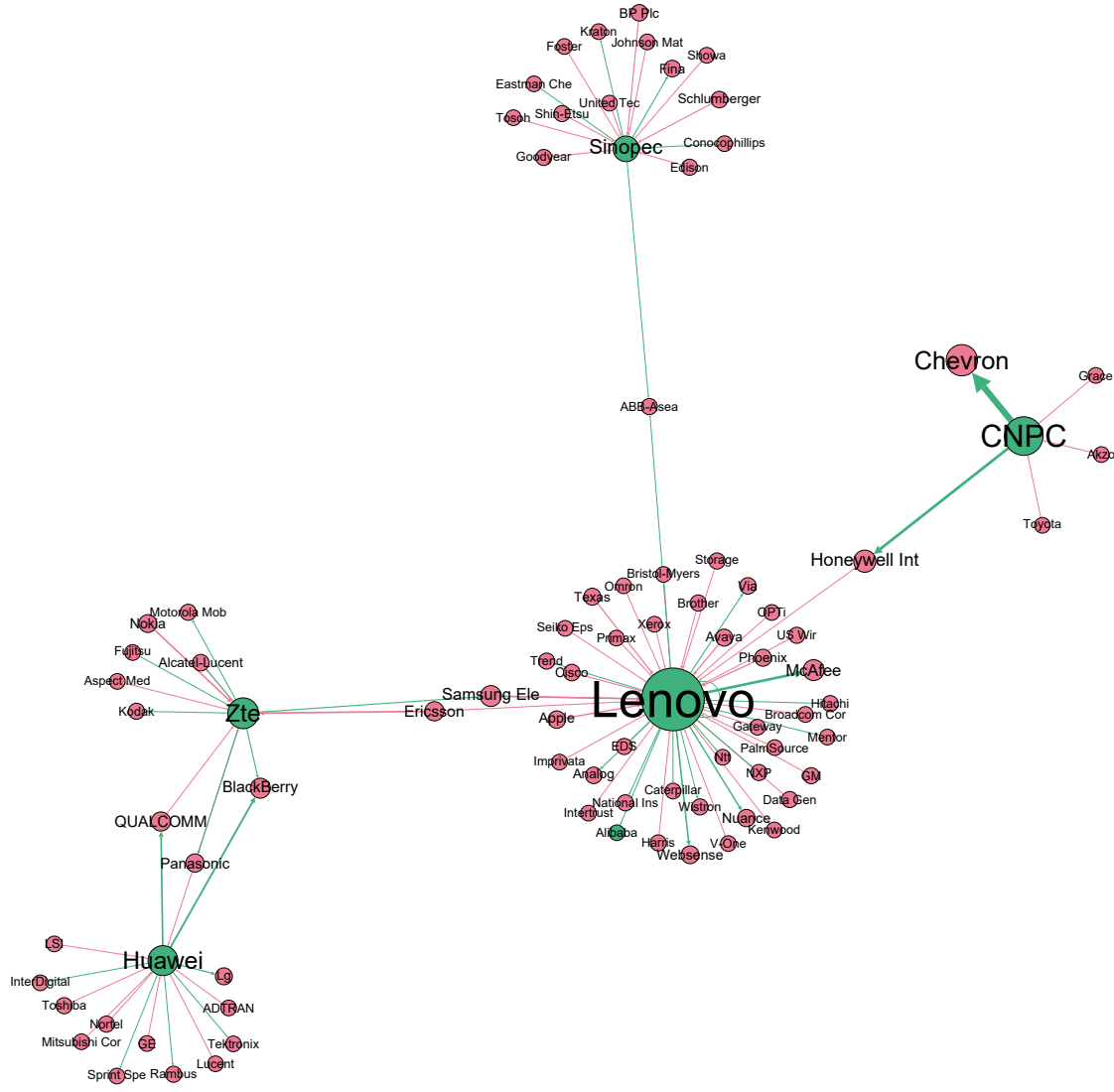
5.2 1998–2006 Period

From 1995 to 2006, China's high-tech industry¹ grew significantly. This increasing significance of China's high-tech industry is manifested by the following statistics. While the share of high-tech goods as a proportion of the total value of imports has increased from 16.5 % (\$21.8 billion) in 1995 to 31.2 % (\$247.3 billion) in 2006, the share of high-tech goods as a proportion of the total value of exports has increased from 6.8 % (\$10.1 billion) in 1995 to 29 % (\$281.5 billion) in 2006. In terms of the trade balance in high-tech products, China had transitioned from a high-tech deficit country to high-tech surplus country (National Bureau of Statistics of China (2007)).

Since 1998, Lenovo (founded in 1984) began filing patents in America. Lenovo is a multinational technology company based in Beijing. Lenovo designs, develops, manufactures, and sells personal computers, tablet computers, smartphones, workstations, servers, supercomputers, electronic storage devices, IT management software, and smart televisions. Lenovo was famous in China for its acquisition of IBM's personal computer division in 2005. Then Chinese media and academia dubbed it as "the snake swallowing the elephant". As of the third quarter of 2020, Lenovo is the biggest personal computer vendor by unit sales, accounting for 25.7 % market share (Gartner (2020)).

¹The high-tech definition used here is set by the State Development and Reform Commission. Ferrantino et al. (2008) High-tech products include: 1. Information chemical products; 2. Medical and pharmaceutical products; 3. Aircraft and spacecraft; 4. Electronic and telecommunications equipment; 5. Computer and office equipment; 6. Medical equipment and meters; 7. Public software service; 8. Other(includes nuclear fuel processing).

Figure 5.3: Patent Citation Network (2001)



As can be seen from the graphs in the appendix, from 1998 to 2000, Lenovo and Sinopec formed two major hubs in the network graphs. However, the number of companies that connects Lenovo increase faster than the the number of companies connecting Sinopec. Figure 5.3 is the patent citation network in 2001. In 2001, Lenovo's weighted degree is 110, with 59 weighted in-degree and 51 weighted out-degree, while Sinopec's weighted degree is 24, with 17 weighted in-degree and 7 weighted out-degree. Lenovo has overtaken Sinopec as the largest node in the network graph. This clearly shows that the information technology (henceforth "IT") industry has become the most innovative industry in China. This phenomenon of the growing number of patents filed by Lenovo aligns with the following statistics. The micro-computer output in China has tripled from 2,914,000 units in 1998 to 8,776,500 units in 2001 (National Bureau of Statistics of China (2002)). Contemporarily, world personal computer sales rose 37% from 93,310,000 units in 1998 to 128,060,000 units in 2001 (Gartner (2000), Gartner (2002)). China's personal computer sales growth outstripped the world's sales growth by a large margin during this period. Based on the statistics, we might come to the conclusion that the huge demand of PC computers might in term push the innovation of the Lenovo, which serves as one explanation for the fact that China's patent filing in the United States had started to move from the energy industry to the IT industry. Actually, this trend continues since then, with other companies like Huawei filing more and more patents each year. Huawei and ZTE (founded in 1987 and 1985, respectively), China's two largest telecommunication giants, also the two linchpins of trade relations between United States and China, made their

patent debuts at the USPTO in 2000 and 2001, respectively. It did not take long for Huawei to become the company that filed the most patents in America.

By 2001, we can see from the bibliographic coupling network graph (figure 5.4), Huawei and ZTE, as well as their competitors form the telecommunications giant component. The computer manufacturing giant component is made up of Lenovo and its competitors. The firms in both the telecommunications giant component and the computer manufacturing giant component all belong to the IT industry sector (gsector==45 according to the GICS). Sinopec and its competitors belong to the petrochemical giant component; while CNPC and its competitors form the petroleum giant component. Both the petrochemical and petroleum firms are categorized into the energy industry (gsector==10 according to the GICS). That is to say, up until 2001, Chinese companies tended to focus on a supposedly narrow field such that the high-tech industry as whole is still fragmented. For example, the petrochemical giant component does not connect with the petroleum giant component. It is also worth mentioning that the telecommunications firms are still not related with the computer manufacturing industry in terms of patent citation. As to the telecommunications industry per se, ZTE and Huawei shared 4 common competitors in their top 10 competitors. This indicates that their technology pursuit in this period is very close.

In 2001, among all the top 2% competitors of Huawei, ZTE, and CNPC identified by the Jaccard index in figure 5.4, only NETGEAR Inc (ranked as ZTE's No.14 forward citation) is linked with the focal Chinese firm (ZTE) in the citation

network. This indicates that these three companies did not learn from their competitors a lot. Neither did their competitors learn from them much. Interestingly, Huawei is ranked as ZTE's No.2 competitor, vice versa. What is more, of Huawei's top 10 competitors, four of which are also ZTE's top 10 competitors. This observation indicates that the business scope of Huawei overlapped significantly with that of ZTE.

Nevertheless, 7 out of Lenovo's top 28 competitors are linked with Lenovo in the citation network; while 6 out of Sinopec's top 20 competitors are connected with Sinopec in the citation network graph. This indicates that these two firms from China's computer manufacturing industry and petrochemical industry, respectively, have been integrated with their competitors through patent citation behavior.

Figure 5.5 is the citation network in 2006, except the small "island" formed by three nodes including Tencent, the nodes in the energy industry and the IT industry form a giant component. It is clear that Huawei, with a weighted degree of 101, is the most prominent node in terms of degree centrality, while the node size of Sinopec has shrunked significantly comparative to those Chinese IT firms. Clearly, the IT sector has overtaken the energy sector as the leading innovative sector in China. During this period, Beijing has focused on helping the Chinese companies move up the industrial value chain. The technological development of the Chinese firms comes not only from their desire to expand the market share, but also from the government's support for the sector. As Beijing made it clear in

its tenth Five-Year Plans for 2000 to 2005: improve the national economy and social IT levels; raise research and development funding to more than 1.5% of GDP, and strengthen sci-tech innovation capabilities, thereby speeding up technological progress.

More importantly, in 1996, Beijing started to support Chinese telecommunications companies and ended special import policies for telecoms equipments to prevent foreign dominance in China's equipment industry. Both the military and the government began to tout Huawei as a national champion. It is unclear why Beijing picked Huawei over ZTE (Gilley (2001)). Nevertheless, this does not imply that the government gave up on ZTE. In 2001, \$1.5 billion contract of China United Network Communications Group ("China Unicom", one of China's three largest state-owned telecommunications carriers) for building a national CDMA network was shared by five foreign companies (Motorola, Lucent, Ericsson, Nortel, and Samsung) as well as ZTE. In order for ZTE to get a share of the contract, China Unicom turned from CDMA20001X to CDMAIS95, a less advanced standard that ZTE already had manufacturing capacity (Iritani (2001)). It is due to this government arrangement, ZTE successfully transformed from a traditional fixed-line equipment vendor to a data, wireless, and optical communication equipment vendor (Hong et al. (2012)).

Since 1996, Huawei pushed its first internationalization in other developing markets like Russia, Thailand, Brazil, South Africa, and etc. Since 2001, Huawei began its second internationalization push to the advanced markets (Ahrens

(2013)). Specifically, Huawei enters the U.S. market in February 2001. My results indicate that Huawei's growing patents are in tandem with its second internationalization push. It is not difficult to understand this, as competing in advanced countries incurs urgent need of intellectual property protection.

Huawei's innovation clout does not come only as windfall of government support, without which its rapid rise could not have happened, though. Huawei first succeeded by reverse-engineering imported network equipment and switching devices. It built its strong cadre of researchers from the start. In the 1990s, it was not uncommon for Chinese companies to establish international joint-venture to import and absorb foreign technology (as well as management skills). Nevertheless, Huawei decided to develop its own technology in house, as it believed that those transferred foreign technology is unlikely to be their cutting-edge technology and Huawei would be better off building its R&D capacity (Ahrens (2013)).

Besides the incentives from the inside, the incentives coming from the outside also contributes to the observed change from the energy sector to the IT sector in the citation networks in this period. An important event worth noticing is that China joined the WTO in December 2001. In order to join the WTO, China had to (1) lower its tariffs for imports, (2) permit foreign firms to sell their products directly in the Chinese markets, and (3) open the finance and telecommunications sector to foreign firms. Facing increased competition from the the foreign firms, Chinese telecommunications firms have to upgrade their products, as well as their technology to survive. The lower tariffs and the increased competition

brought about upon China becoming a member of WTO also changed the relative importance of different sectors and of the state versus non-state industrial sectors. As tariffs became lower and foreign companies entered the Chinese market, the Chinese firms (especially those in the telecommunications and finance sector) would expectedly become more efficient, which in turn resulted in the relative ascendancy of the non-state (IT) sector relative to the state (energy) sector (Chow (2003)).

There are three giant components in the bibliographic coupling network in 2006 (figure 5.6): the IT giant component, the petrochemical giant component and the petroleum giant component. The IT giant component includes three hubs: Huawei, Lenovo, and Zte. The Petrochemical giant is composed of Sinopec and firms that linked to it. The petroleum giant component includes CNPC, which is linked through Sun Microsystems Inc. to Byd, which is another high tech companies with its main business in industries related to electronics, automobiles (especially battery-powered automobiles), new energy and rail transit.

The graph clearly shows that the telecommunications industry and the computer manufacturing industry had connected with each other. This merging in the bibliographic coupling networks first happened in 2002. The trend of the two industries merging continued well into 2013. Another salient trend we can observe in the graphs is that while the number of competitors for the IT companies (including both the telecommunications firms and computer manufacturing firms) continued to grow, the number for the energy companies kept dwindling—both

are reflective of the phenomenon in the patent citation networks.

5.3 2007–2013 Period

The trend of industry upgrade from the energy industry to the information technology continues into the 2010s. In this period, Tencent and Alibaba, two e-commerce companies have been filing more and more patents at the USPTO each year. Figure 5.7 shows the patent citation network graph for 2013. All the nodes in the graphs form a giant component. As is shown in the graph, the links connecting energy firms have decreased to only 3. By comparison, the edges linking the IT firms have grown exponentially insofar as the graph is very not very legible. Besides, most of the Chinese tech firms are bibliographically coupled as they share a great number of citing patents. The coupling strengths are extremely high if we use all the citation data to do the graphs. From all the citation network graphs, we can conclude that patents filed by Chinese companies cite significantly more patents filed by companies outside of China than vice versa.

Over the years in this period, BOE Technology, Alibaba Group, Tencent are three companies that gained much momentum besides Huawei, which continued to grow its patents and keep its dominant and predominant position in the patent network graphs. BOE is an internet of things (IoT) company (founded in 1993) specializing in interface devices, smart IoT systems and smart medicine & Engineering Integration. Its products are more downstream as compared with other

Chinese firms in the IT industry. By 2020, more than a quarter of global display panels have been made by BOE (BOE (2021)). It is a company that gives R&D a high priority. Even though BOE has not been implicated in the US-China trade war, it is vulnerable if the trade war escalates due to the facts that: (1) among the top ten shareholders, 9 of which are state-owned entities, (2) the firm relies on US firms such as 3M, Corning and Applied Materials to supply the most critical equipment and materials to make display panels (Hu (2019)). As to Alibaba and Tencent, China's two most valuable publicly listed companies (Lim et al. (2021)), which are already involved in the US-China trade war, together with Baidu Inc (founded in 2000, China's answer to Google), they form the so-called "BAT" (a three-letter acronym of the three names) triumvirate.

Alibaba, one of the tech trio, founded in 1999, first linked buyer and sellers of goods. It introduced more business functions as its technology advanced, including but not limited to advertising, finance, marketing, logistics, and emerging ones such as product recommenders, affiliate marketing, and social media influencers (Zeng (2018)). Alibaba launched Taobao (its C2C business model) and Ali-pay (its third-part mobile and online payment platform) in 2003 and 2004, respectively. By then, Alibaba has set up its giant e-commerce business and technology base. Since 2007, it has been filing more and more patent in the United States, which is in tandem with its business growth. Its annual revenue has grown more than five times from 6.67 billion Chinese yuan to 34.517 billion Chinese yuan from 2010 to 2013. For fiscal year 2020, its annual revenue has reached 509.711 billion Chinese yuan (Statista (2021)). Although it is difficult, if not impossible to say that

its technology development induces its exponential growth in business, or vice versa, based on only its patents in the United States, we can safely conclude that its business and technology grew simultaneously.

Tencent, another one of tech trio, founded in 1998, a multinational technology conglomerate holding company specializing in social network, web portals, mobile games, multiplayer online games, music, internet services, payment systems, and smartphones, first filed its patents in America in 2005. It starts as an social network company famous for its QQ, an instant messaging software service and web portal. It was not until 2007 did it it began to enter the online game market seriously (Einhorn and Stone (2011)). As of 2019, gaming has been its biggest source of revenues (Li (2019)). Tencent is the patent company of Riot Games Inc, which created the popular videogame "League of Legends". Tencent also has stakes in Activision Blizzard Inc. and Epic Games Inc., which are creators of world-famous games "World of Warcraft" and "Fortnite", respectively (Restuccia and Yang (2020)). Ever since its foundation, Tencent has gained ascendancy in China's IT industry due to its supremacy as the largest communication and social platforms in China. As of mid-2020, WeChat, a super-app that provides encrypted messaging, payments and other services, has more than 1.2 billion monthly active user account (Tencent Holdings Limited (2020b)). Due to this absolute advantage, Tencent had long been technologically inert. As a result, it is often assaulted by other Chinese tech firms and observers as an copycat. However, from the network graphs, we can see that it has gradually increased its patent counts in America, though it still lags behind other tech companies like Alibaba and BOE.

Actually, its adoption of simultaneous product development and rapid “launch-test-improve” circle in its R&D process has produces fruitful results in leading in business model innovation. Two cases in point are: WeChat added mobile payments service (WeChat Pay) in 2013, while Facebook announced online payment in 2015. WeChat allowed users to set up online stores (micro-shop) in 2014, while Facebook allowed retails to sell from Facebook pages in 2015 (Hermione (2015)). I am confident that it is a matter of time for this tech Goliath to make its name outside of China.

Since 2014, China has witnessed a revolutionizing change in its retail payment system, characterized by Tencent’s Wechat Pay and Alibaba’s Alipay leapfrogging the card-based system. Alipay and Wechat Pay are built upon digital wallets, QR codes (two-dimensional bar codes) and run through their own Alibaba and Tencent systems, respectively. The number of Alipay’s annual active users served by Ant Group (a subsidiary of Alibaba) and its nine local e-wallet partners hit about 1.3 billion during the 12 months ended March 31, 2020 (Alibaba Group (2020)). As of the fourth quarter of 2019, Tencent had over 1 billion average daily transactions using Wechat Pay, which covered over 800 million monthly active users, among which were over 50 million monthly active merchants (Tencent Holdings Limited (2020a)). The prevalence of these two mobile payment systems is best illustrated by the phenomenon that beggars has replaced tin cups with QR codes to receive money. The trendy development of use of mobile payment has disintermediated the banks in China. As the prevalence of Alipay and Wechat Pay go beyond the Chinese border, this financial payments infrastructure built upon mo-

mobile payment systems can be part of the wider vision of China's Belt and Road Initiative, strengthening China's economic connections across the world (Klein (2020)).

Baidu Inc. only has one patent approved by the USPTO in 2007. It is not sure why Baidu does not have an incentive to file patents in the United States. A judicious guess would be that Baidu is the Chinese search engine monopoly (Alphabet's Google and other search engines are banned in China), the lack of competition gives rise to the lack of innovation. It is worth mentioning that all the three Chinese tech giants were just infants when the dot.com bubble collapsed in 2000, so they avoided most of the pain.

Figure 5.8 is the bibliographic coupling network for 2013. Still, in the graph I have two giant components: the IT giant component and the energy giant component. Comparing with figure 5.6, the communication sector further integrates with the computer manufacturing sector.

In 2013, the top 2 competitors of Huawei identified by the Jaccard index are Nokia and Ericsson. That is to say, Huawei cited previously filed patents that were also heavily cited by parent companies of Nokia and Ericsson, both of which are identified by business analysts as the closest rivals to Huawei (Stacey (2019), Jeans (2020)). Using the Jaccard index to identify competitors looks very great. However, there is one caveat: the rank of the competitors identified by such method might not necessarily be the same as the true rank of the company's competitors by whatever criteria. This is understandable as those conglomerates tend to special-

ize in multiple fields, and the fact the patent filings in each year might not reflect a company's business scope well. However, I still believe that the competitors identified by such a method are legitimate. Figure 5.9 shows Huawei and its top 12 competitors' backward citations in 2013. The green nodes indicates Huawei and its 12 competitors, while the burgundy nodes stands for their backward citations. The size of the nodes are proportional to their weighted in degrees. The graph shows that Huawei and its top 12 competitors' backward citations overlapps significantly.

It is also important to note that although American firms accounts for 70% of Huawei's top 20 competitors in 2013 (see appendix for more detail), there are no US rival to Huawei when it comes to supplying equipment for 5G mobile networks. United States were dominant in the days of landline telecoms. The passage of The Telecommunications Act in 1996 has promoted and created more competition in the US telecommunications industry by allowing companies to develop and use their own network technologies. Meanwhile, European firms all agreed to use GSM, which later become the worldwhile standard for mobile communications. Due to the fierce competition at home, US firms looked to boost their revenue growth by selling into the burgeoning and booming Chinese market, which entailed the US products to be manufactured locally in China and technology be shared with the Chinese partners (Stacey (2019)).

As discussed above, forward citation can serve as the simplest yet still informative proxy for technological impact. By comparing the mean forward citation

of Huawei and its top 12 competitors that are identified by the Jaccard Index in 2013 (figure 5.10 and figure 5.11), I find that the technological impact of Huawei's patents has increased significantly comparing with its competitors during the past decade, as the gap between the two lines are closing over time. Still, a caveat needs noticing here is that the mean forward citation in the latest years might not be as informative as it should be due to the truncation problem inherent in the patent

²From left to right, from top to bottom are the graph between Huawei and its top 6 competitors identified in 2013: Telefonaktiebolaget LM Ericsson, Nokia Corporation, InterDigital Inc., Nec Corporation, Cisco Systems Inc., Fujitsu Ltd., in that order.

data. As time goes by, the forward citation a patent receives will (very much) likely to increase. This implies that the forward citation in the recent years is underestimated to some extent. Even so, we can still conclude that Huawei patents' technological impact has enhanced over time, given that I use forward citation data as late as mid-2017 when calculating the mean forward citation. Conversely, I can check the forward citations of Sinopec and its top 12 competitors (also identified by the Jaccard index in 2013). As to the energy industry, I found that while the mean forward citation of Sinopec's patents filed in 1989, 1992, and 1998 is higher than that of almost all its top 12 competitors, Sinopec's mean forward citation since 1999 has been slightly lower than, if not remarkably lagging behind, that of its competitors since 1999. This indicates that Sinopec's technological impact has been lower than its competitors since 1999. The findings from the forward citation are consistent with my previous findings from the citation network graph that China's most technology intensive industry has transformed from the energy sector to the IT sector, especially the telecommunications sector. I am careful not to over-generalize here. Still, the mean forward citation for each company can shed light on the technological impact of the its patents. The appendix provides the comparison between the other top 6 Chinese firms (that files most patents at the USPTO) and its competitors identified by the Jaccard index in 2013.

³From left to right, from top to bottom are the graph between Huawei and its top 7-top 12 competitors identified in 2013: Broadcom Corp., Lenovo Group Ltd., Juniper Networks Inc., Brocade Communications Systems Inc., CenturyLink Inc., Nuance Communications Inc., in that order.

Figure 5.4: Bibliographic Coupling Network (2001)

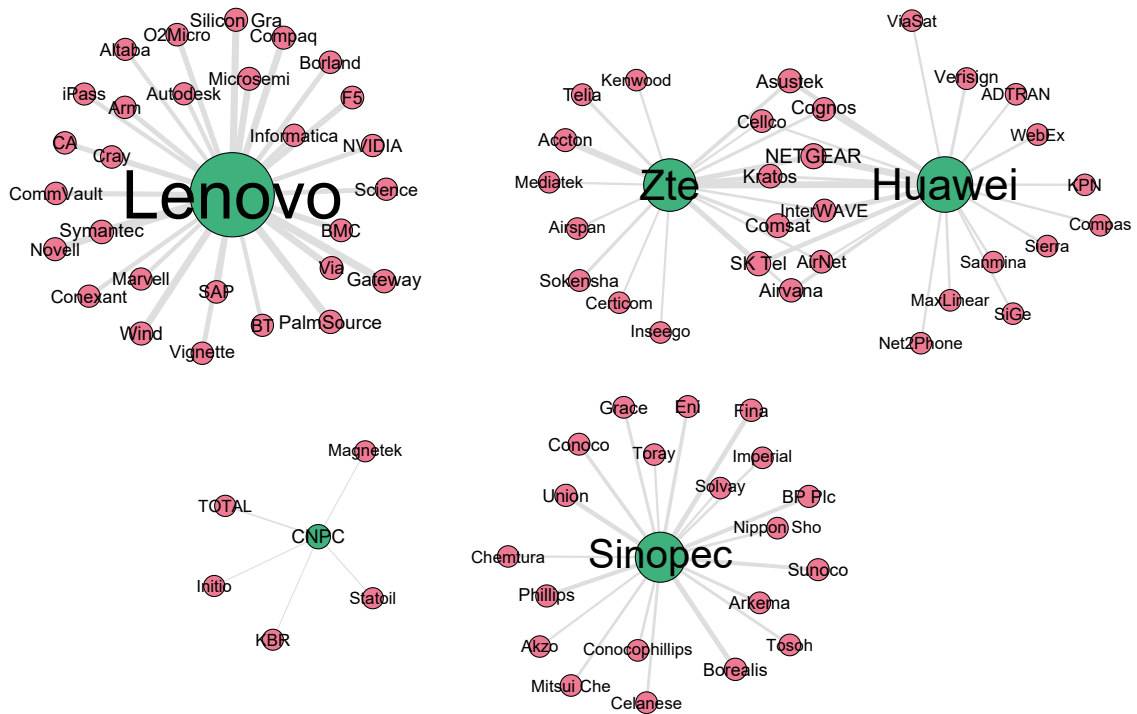


Figure 5.5: Patent Citation Network (2006)

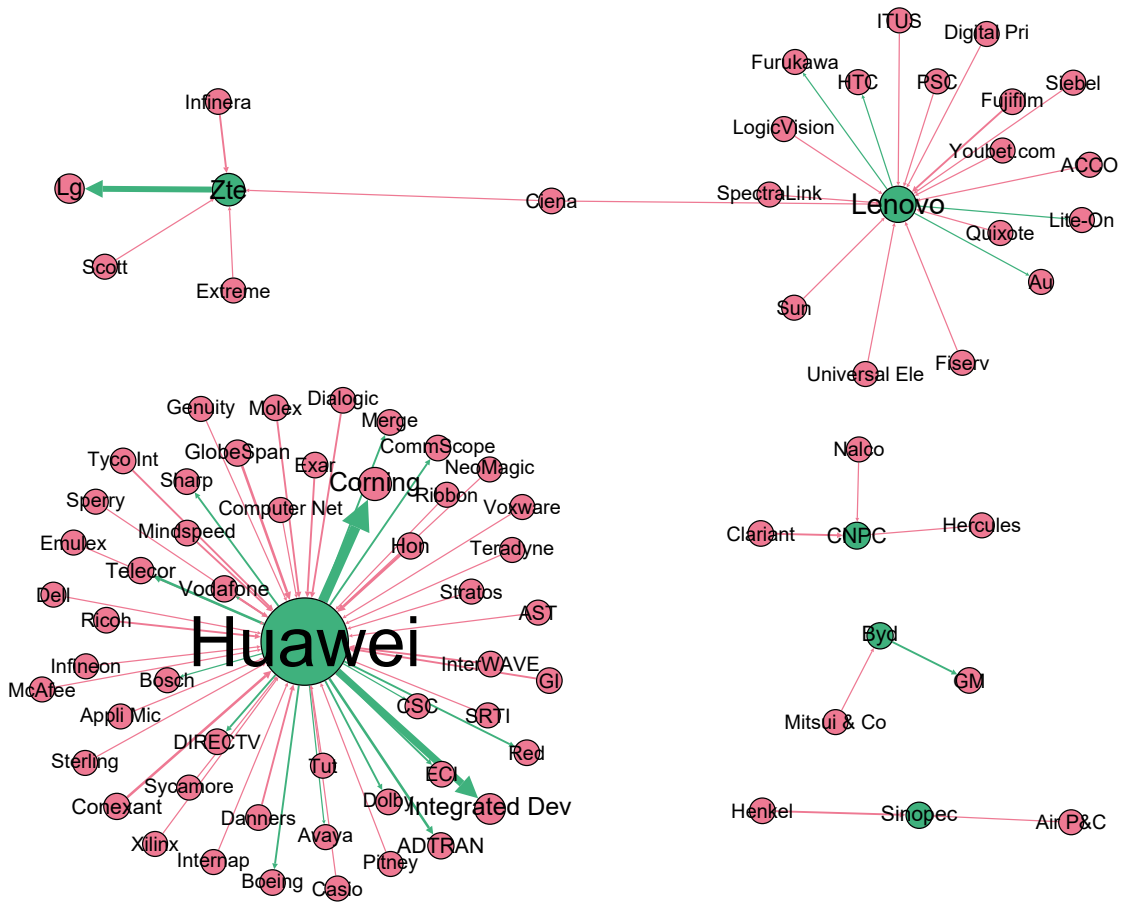


Figure 5.6: Bibliographic Coupling Network (2006)

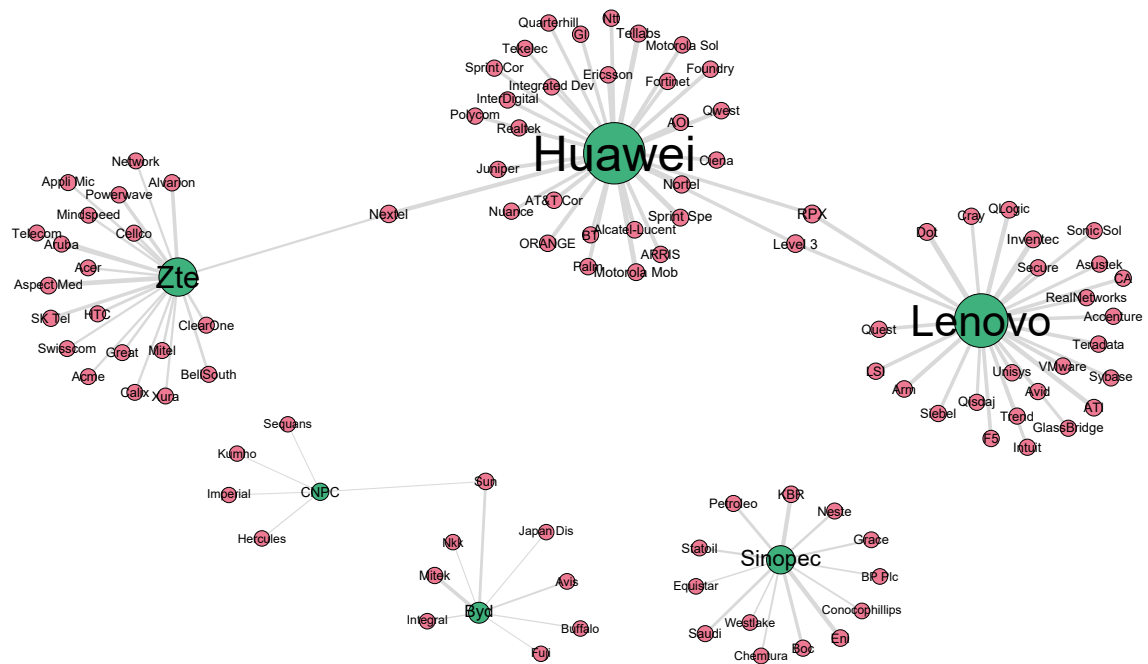


Figure 5.7: Patent Citation Network (2013)

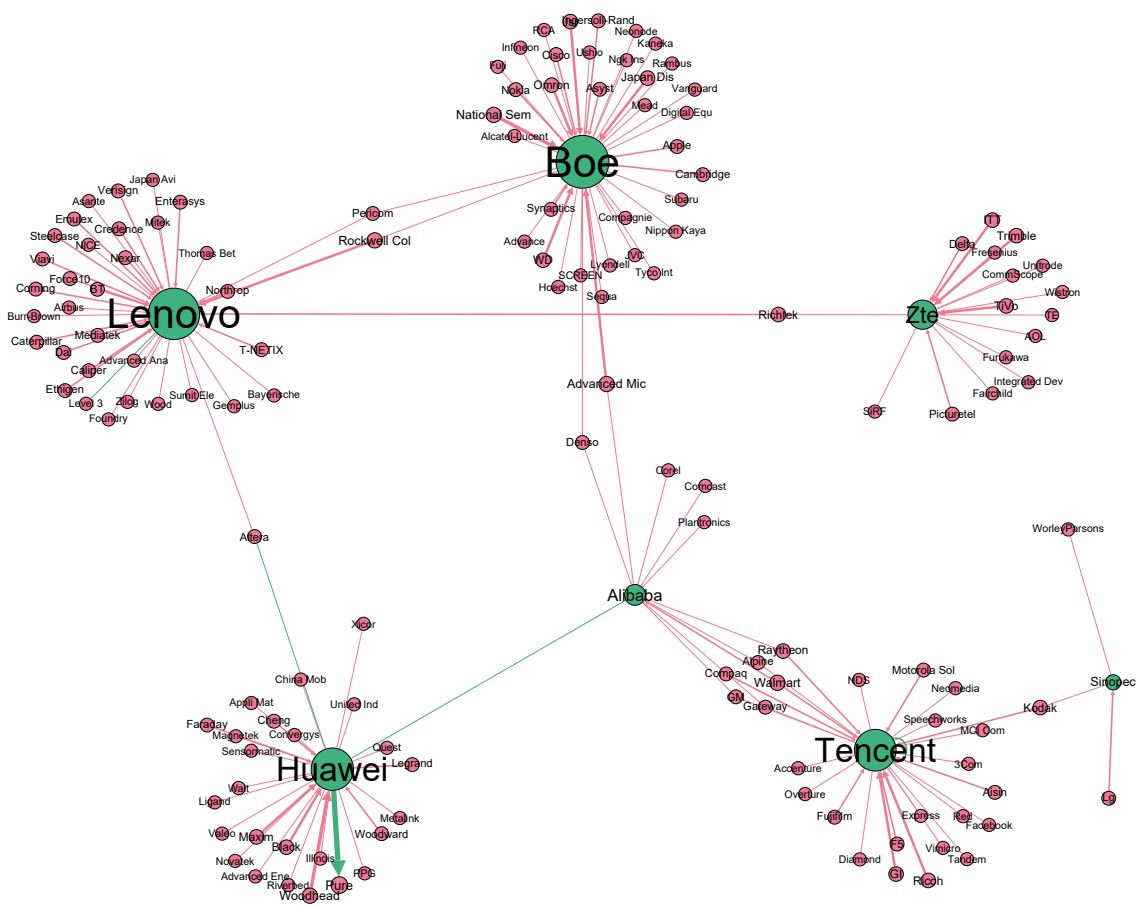


Figure 5.8: Bibliographic Coupling Network (2013)

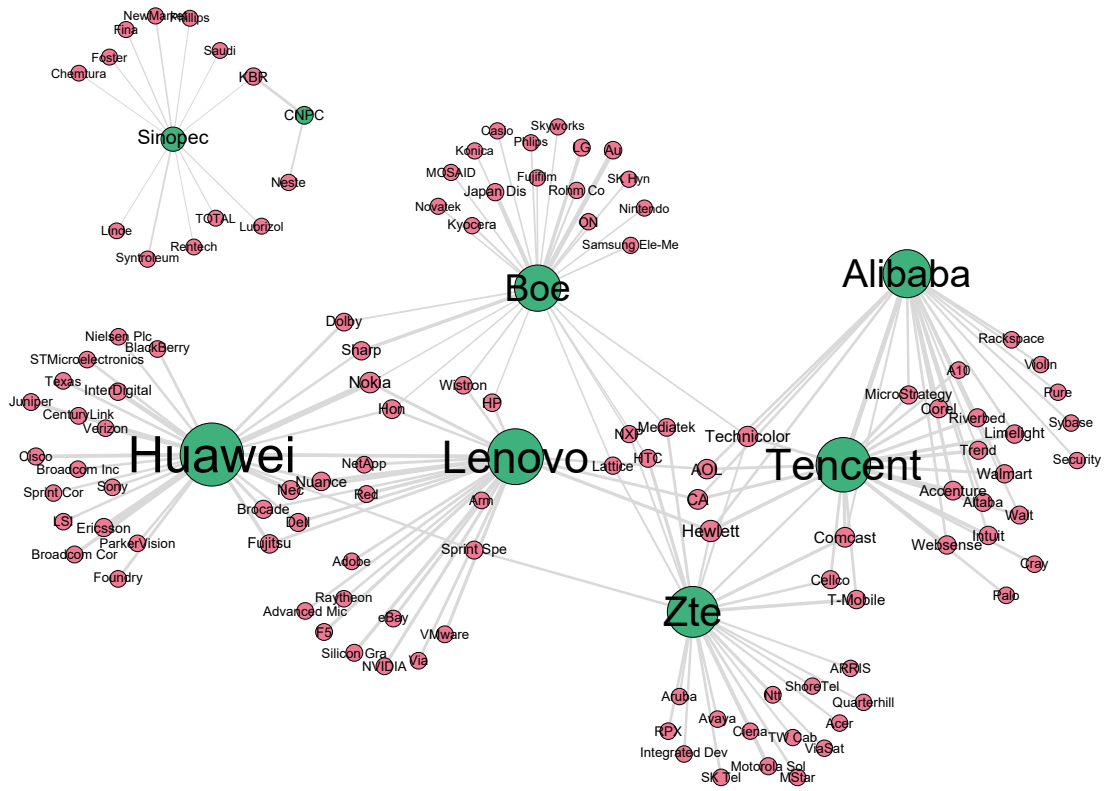


Figure 5.9: Huawei and its top 12 Competitors' Backward Citation Network (2013)

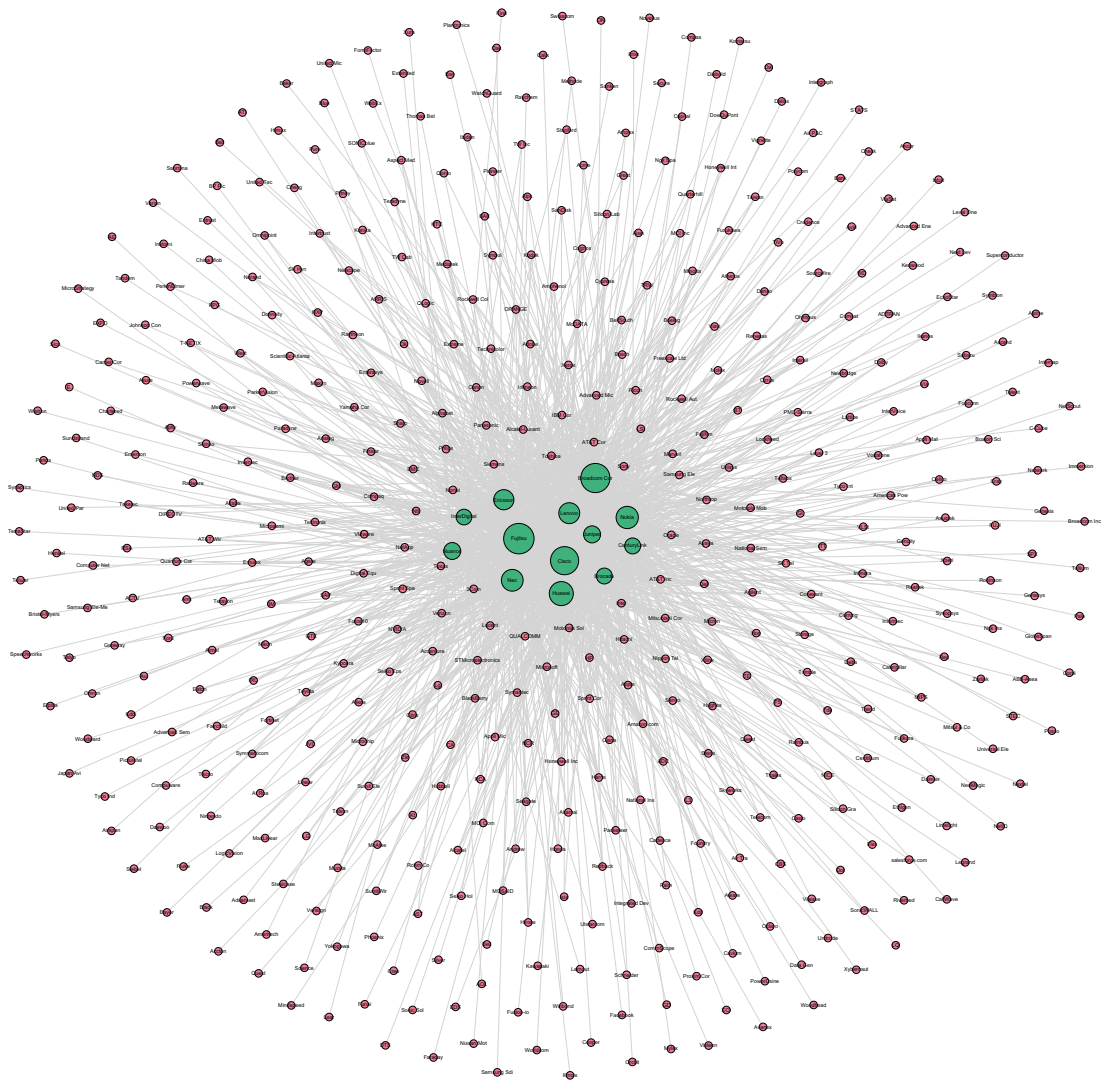


Figure 5.10: Mean Forward Citation–Huawei and its Competitors (1)

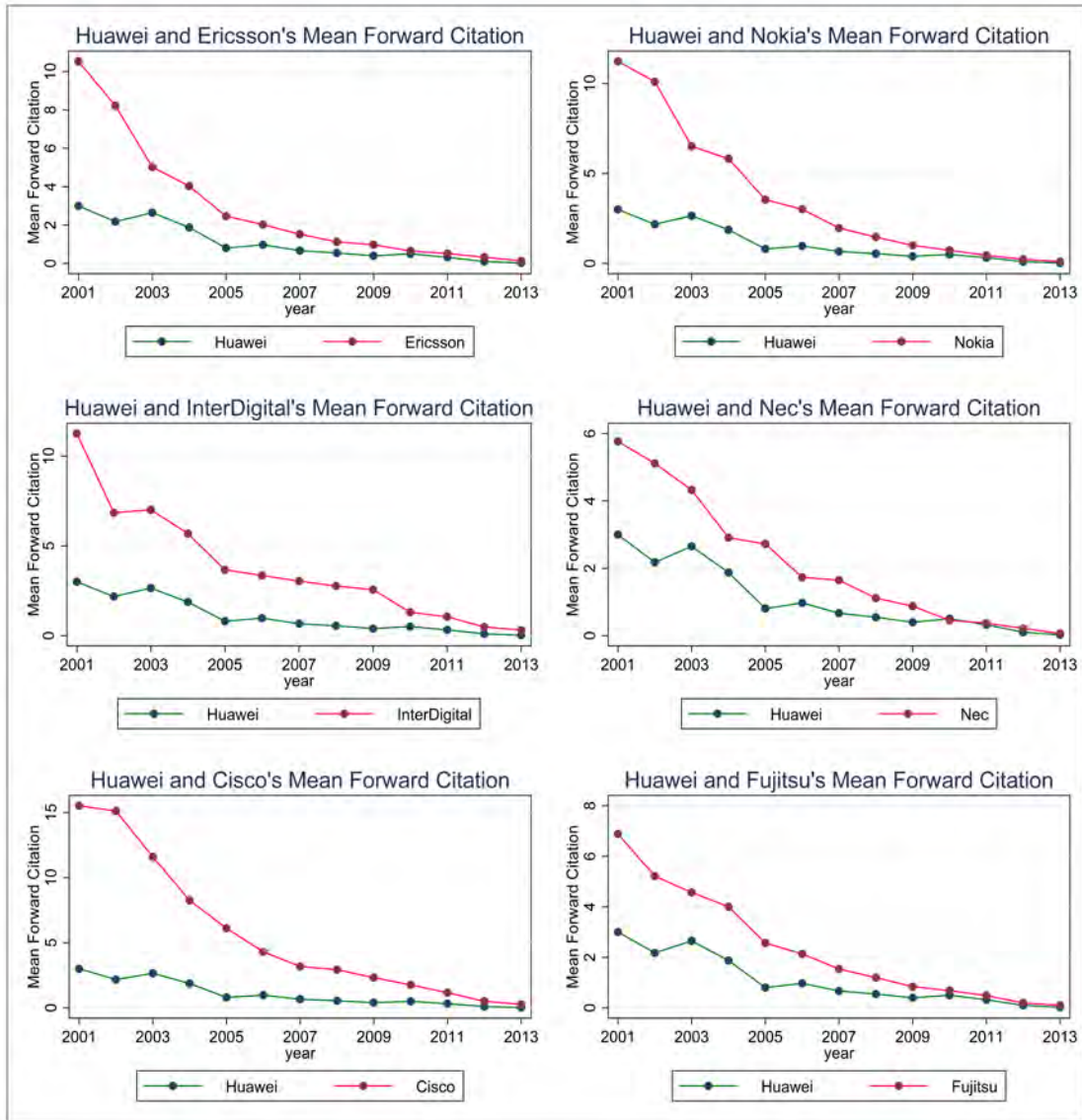
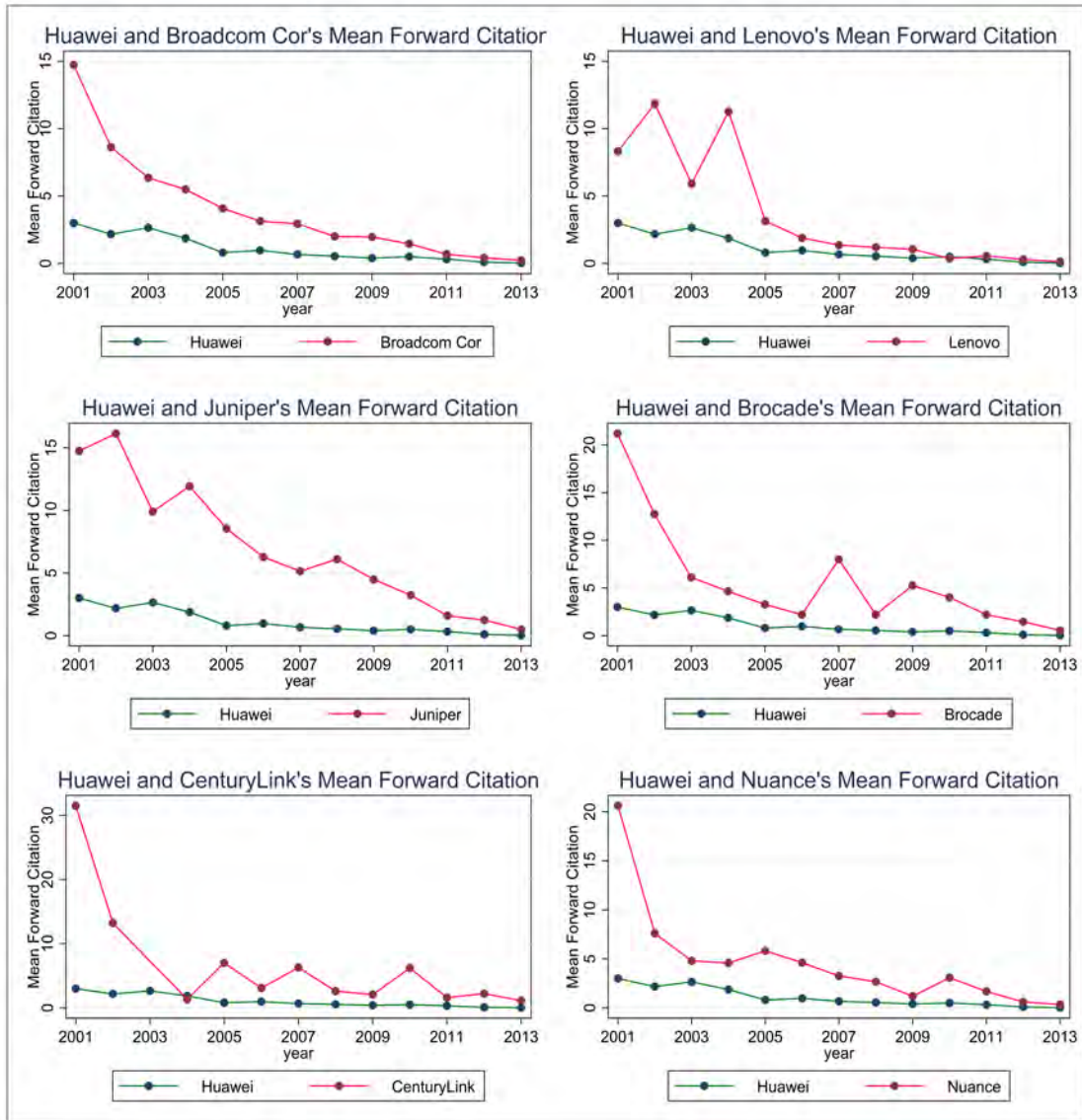


Figure 5.11: Mean Forward Citation–Huawei and its Competitors (2)



CHAPTER 6

DISCUSSION

One of the strength of this paper is the use of Jaccard index, which captures well the competitors of Chinese firms. For example, the Jaccard index in 2013 indicates that Huawei competes most fiercely with Ericsson and Nokia. The Jaccard indices for the Huawei-Ericsson pair and Huawei-Nokia pair are significantly higher than the Jaccard indices for Huawei's other bibliographic coupling pairs. Ericsson and Nokia are arguably two of Huawei's closest rivals, especially in the field of 5G mobile network. Another strength of this paper is that the use of the only top Chinese firms that have been filing patents in the United States. By using just those 12 companies as our focal firms, the patent citation networks serves a big motion picture, showing how China's energy firms, computer manufacturing firms, telecommunication firms, and the E-commerce giants has developed and innovated over time.

However, there are still a few limitations that are inherent in this paper. As we have presented, this paper uses only the Chinese firms' US patents, which is sparse by comparison with their Chinese patents. By doing so, we cannot cover all the sectors in our citation networks. For instance, the Chinese pharmaceutical firms has not filed patents at the USPTO by 2013. Besides, when downloading patents from Google Patent database, I use key words to decide whether a patent was assigned to a specific company. As a result, if a patent is assigned to a subsidiary of a company that does not have a company name that includes the key-

words I use, I will definitely lose track of such a patent. It is understandable that such patents exist, though I do not know how many there are. That is to say, the patents downloaded from Google Patents are underestimated. Last but not least, since the UVA granular data only includes patents that are assigned to public companies. In both my citation network graphs and bibliographic coupling network graphs, all the nodes connecting the Chinese firms are public companies. That is to say, the graphs only show the relation between Chinese firms (both public and private) and non-Chinese public firms.

Although I aim to research whether China's technology rising has posed as a serious threat to the United States, this paper does not provide a causal inference for that. For future research, it would be interesting to check whether the rising of Chinese patents at the USPTO has affected/ changed American firms' citation behavior and whether the US firms have cited more/less Chinese patents accordingly. Besides, further research can focus on whether the Chinese patents in the United States have led to US firms filing less/more patents in the related field. Last but not least, it will be interesting to focus on patents in a specific field to see what is the most important technology and whether the United States is still the leading player in this field.

CHAPTER 7

CONCLUSION

This paper tracks the knowledge flow concerning the Chinese patent at the USPTO, using basic network concepts, network graphs, together with a historical approach to analyze the industry evolution in China. Besides, by developing a Jaccard index based on the patent bibliographic coupling, this paper identifies the Chinese companies' competitors, which are proved to be very much close to its real competitors. It is worth mentioning that although the network graphs give a quite accurate and broad sense of the relationship between different companies, I have to admit that without our prior, it would be difficult, if not impossible to disentangle the connection between the different nodes. Without the prior, based on only the business scope of the companies, I could come to spurious at best, conclusions. That is why I employ the historical approach. My analysis shows that the combination of network graphs and the historical method serves as a quite straightforward yet still accurate approach in dealing with industry evolution. My results show that: in the 1990s, the Chinese petrochemical files most, if not all the Chinese patents in America; in early 2000s, the computer manufacturing company Lenovo gathered significant momentum in terms patents at the USPTO; however, it did not take long for the telecommunications industry to file the most patents in the United States. Recently, we also see the rise of the e-commerce firms like Alibaba and Tencent. Although I cannot find the specific strength of the Huawei, Alibaba, and Tencent from just counting their patents, the history of

those companies in their fields still shows that they have risen as a formidable rival to other firms in the same field. This might partly explains why they have been embroiled in the trade war between China and the United States.

This paper is my first endeavor to explore the industry evolution in China. Even though it gives us a broad sense of what we are after, I have to admit that my analysis might be too over-representative, as my data is sparse in that only a handful of Chinese firms file patents in the United States. For future research, it would be interesting for researchers to use the same approach to analyze industry development and evolution based on patent data from not only the UPSTO, but also from China National Intellectual Property Administration, European Patent Office, Japan Patent Office, etc. Besides, future research could think about more quantitative methods to piece together relationship and possible dynamic among patent-pairs.

CHAPTER 8
BIBLIOGRAPHY

BIBLIOGRAPHY

- Nathaniel Ahrens. China's competitiveness: Huawei. *The Center for Strategic and International Studies*, February 2013. URL https://csis-website-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130215_competitiveness_Huawei_casestudy_Web.pdf.
- Michael B Albert, Daniel Avery, Francis Narin, and Paul McAllister. Direct validation of citation counts as indicators of industrially important patents. *Research policy*, 20(3): 251–259, 1991.
- Juan Alcacer and Michelle Gittelman. Patent citations as a measure of knowledge flows: The influence of examiner citations. *The Review of Economics and Statistics*, 88(4):774–779, 2006.
- Alibaba Group. Fy 2020 annual report. 2020. URL <https://doc.irasia.com/listco/hk/alibabagroup/annual/2020/ar2020.pdf>.
- All-China Federation of Industry and Commerce. 2015 China top 500 private enterprises list, january 2018a. URL http://www.acfic.org.cn/zzjg_327/nsjg/jjb/jjbsjgk/201801/t20180125_51045.html.
- All-China Federation of Industry and Commerce. 2016 China top 500 private enterprises list, january 2018b. URL http://www.acfic.org.cn/zzjg_327/nsjg/jjb/jjbsjgk/201801/t20180125_51040.html.
- All-China Federation of Industry and Commerce. 2017 China top 500 private enterprises list, january 2018c. URL http://www.acfic.org.cn/zzjg_327/nsjg/jjb/jjbsjgk/201801/t20180125_51039.html.
- All-China Federation of Industry and Commerce. 2018 China top 500 private enterprises

- list, august 2018d. URL http://www.acfic.org.cn/zzjg_327/nsjg/jjb/jjbgzhdzt/2018my5bq/2018my5bq.bgbd/201808/t20180829_55653.html.
- All-China Federation of Industry and Commerce. 2019 China top 500 private enterprises list, august 2019. URL http://www.acfic.org.cn/zzjg_327/nsjg/jjb/jjbgzhdzt/2019my5bq/2019my5bq.bgbd/201908/t20190822_138379.html.
- All-China Federation of Industry and Commerce. 2020 China top 500 private enterprises list, september 2020. URL http://www.acfic.org.cn/zzjg_327/nsjg/jjb/jjbgzhdzt/2020my5bq/2020my5bq.bgbd/202009/t20200910_244590.html.
- BOE. Company profile, February 2021. URL <https://www.boe.com/en/about/companyProfile>.
- Stefano Breschi and Francesco Lissoni. Knowledge networks from patent data. In *Handbook of quantitative science and technology research*, pages 613–643. Springer, 2004.
- Chaomei Chen and Diana Hicks. Tracing knowledge diffusion. *Scientometrics*, 59(2):199–211, 2004.
- Gregory C Chow. Impact of joining the WTO on China’s economic, legal and political institutions. *Pacific Economic Review*, 8(2):105–115, 2003.
- Cornell University Library. Patent searching: Home, february 2021. URL <https://guides.library.cornell.edu/patents>.
- Dirk Czarnitzki, Katrin Hussinger, and Cédric Schneider. “Wacky” patents meet economic indicators. *Economics Letters*, 113(2):131–134, 2011.
- Bob Davis and Katy Stech Ferek. U.S. moves to cut off chip supplies to Huawei. *WSJ*, may 2020. URL <https://www.wsj.com/articles/u-s-moves-to-cut-off-chip-supplies-to-huawei-11589545335>.
- (Bruce Einhorn and Brad Stone. Tencent: March of the penguins. *Bloomberg*, august 2011.

URL <https://www.bloomberg.com/news/articles/2011-08-04/tencent-march-of-the-penguins>.

Michael J Ferrantino, Robert Koopman, Zhi Wang, Falan Yinug, Ling Chen, Fengjie Qu, and Haifeng Wang. Classification and statistical reconciliation of trade in advanced technology products: the case of China and the United States. *Available at SSRN 1132748*, 2008.

Eugene Garfield. Citation indexes for science. *Science*, 122(3159):108–111, 1955.

Gartner. GartnerGroup’s dataquest says worldwide PC market topped 21 percent growth in 1999, january 2000. URL <https://tech-insider.org/statistics/research/2000/0124.html>.

Gartner. Gartner Dataquest says 2001 is a year battered PC vendors would rather forget, january 2002. URL <https://tech-insider.org/statistics/research/2002/0117.html>.

Gartner. Gartner says worldwide PC shipments grew 3.6% in third quarter of 2020, october 2020. URL <https://www.gartner.com/en/newsroom/press-releases/2020-10-12-gartner-says-worldwide-pc-shipments-grew-3-point-six-percent-in-the-third-quarter-of-2020>.

Bruce Gilley. Huawei’s fixed line to Beijing. *Far Eastern Economic Review*, pages 94–98, January 2001. URL http://www.web.pdx.edu/~gilleyb/Huawei_FEER28Dec2000.pdf.

Hermione. Tencent’s growth through accelerated innovation processes, december 2015. URL <https://digital.hbs.edu/platform-rctom/submission/tencents-growth-through-accelerated-innovation-processes/#:~:text=Through%20its%20accelerated%20innovation%20processes,will%20win%20over%20Chinese%20consumers>.

Yu Hong, François Bar, and Zheng An. Chinese telecommunications on the threshold of

convergence: Contexts, possibilities, and limitations of forging a domestic demand-based growth model. *Telecommunications Policy*, 36(10-11):914–928, 2012.

Minghe Hu. How a chinese accountant turned a dying state-owned factory into BOE Technology Group – world’s no 1 display maker supplying Apple, Huawei. *South China Morning Post*, august 2019. URL <https://www.scmp.com/tech/gear/article/3024664/how-chinese-accountant-turned-dying-state-owned-factory-worlds-no-1>.

Mu-Hsuan Huang, Li-Yun Chiang, and Dar-Zen Chen. Constructing a patent citation map using bibliographic coupling: A study of Taiwan’s high-tech companies. *Scientometrics*, 58(3):489–506, 2003.

Shiu-Wan Hung and An-Pang Wang. Examining the small world phenomenon in the patent citation network: A case study of the radio frequency identification (RFID) network. *Scientometrics*, 82(1):121–134, 2010.

Evelyn Iritani. Telecoms key test of China’s accessibility. *Los Angeles Times*, august 2001. URL <https://www.latimes.com/archives/la-xpm-2001-aug-05-fi-30864-story.html>.

David Jeans. Huawei’s rivals are already filling a \$27 billion hole left by US sanctions. *Forbes*, October 2020. URL <https://www.forbes.com/sites/davidjeans/2020/10/09/huawei-rivals-nokia-ericsson-27-billion-us-sanctions/?sh=46d66aa9de48>.

Maxwell Mirton Kessler. Bibliographic coupling between scientific papers. *American documentation*, 14(1):10–25, 1963.

Aaron Klein. China’s digital payments revolution. *Brookings Institution*, April 2020. URL https://www.brookings.edu/wp-content/uploads/2020/04/FP_20200427_china_digital_payments_klein.pdf.

Patrick Kline, Neviana Petkova, Heidi Williams, and Owen Zidar. Who profits from patents? Rent-sharing at innovative firms. *The Quarterly Journal of Economics*, 134(3):1343–1404, 2019.

- Paul Krugman. Increasing returns and economic geography. *Journal of political economy*, 99(3):483–499, 1991.
- Josh Lerner and Amit Seru. The use and misuse of patent data: Issues for corporate finance and beyond. Technical report, National Bureau of Economic Research, 2017.
- Shan Li. Facebook shift nods to example of chinese super-app WeChat. *WSJ*, march 2019. URL <https://www.wsj.com/articles/facebook-shift-nods-to-example-of-chinese-super-app-wechat-11551972136>.
- Xin Li, Hsinchun Chen, Zan Huang, and Mihail C Roco. Patent citation network in nanotechnology (1976–2004). *Journal of Nanoparticle Research*, 9(3):337–352, 2007.
- Dawn Lim, Jing Yang, Gordon Lubold, and Alexander Osipovich. U.S. weighs adding Alibaba, Tencent to China stock ban. *WSJ*, january 2021. URL <https://www.wsj.com/articles/u-s-considers-adding-alibaba-tencent-to-china-stock-ban-11609961075>.
- Michal Meidan. The structure of China’s oil industry: Past trends and future prospects. *Oxford Institute for Energy Studies*, 2016.
- Mary Ellen Mogee and Richard G Kolar. Patent co-citation analysis of Eli Lilly & Co. patents. *Expert Opinion on Therapeutic Patents*, 9(3):291–305, 1999.
- Francis Narin. Patents as indicators for the evaluation of industrial research output. *Scientometrics*, 34(3):489–496, 1995.
- National Bureau of Statistics of China. China Statistical Yearbook 2001 . pages 13–22, 2002. URL <http://www.stats.gov.cn/english/statisticaldata/yearlydata/YB2002e/ml/indexE.htm>.
- National Bureau of Statistics of China. China Statistical Yearbook 2007 . pages 21–52, 2007. URL <http://www.stats.gov.cn/tjsj/ndsj/2007/indexeh.htm>.
- Alan Pilkington, Romano Dyerson, and Omid Tissier. The electric vehicle: Patent data as

- indicators of technological development. *World Patent Information*, 24(1):5–12, 2002.
- Gene Quinn. Patentability: The novelty requirement of 35 U.S.C. 102. June 2017. URL <https://www.ipwatchdog.com/2017/06/10/patentability-novelty-requirement-102/id=84321/#:~:text=One%20of%20the%20most%20common,that%20the%20invention%20is%20new>.
- Andrew Restuccia and Jing Yang. Trump executive orders target TikTok, WeChat apps. *WSJ*, August 2020. URL <https://www.wsj.com/articles/senate-votes-to-ban-tiktok-on-government-issued-phones-11596760843>.
- Henry Small. Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for information Science*, 24(4): 265–269, 1973.
- Kiran Stacey. Why is there no US rival to compete with Huawei? *Financial Times*, April 2019. URL <https://www.ft.com/content/18d3823a-65f2-11e9-9adc-98bf1d35a056>.
- Statista. Annual revenue of Alibaba group from financial year 2010 to 2020, February 2021. URL <https://www.statista.com/statistics/225614/net-revenue-of-alibaba/#:~:text=Alibaba's%20annual%20revenue%20FY%202010%2DFY%202020&text=In%20the%20fiscal%20year%20ending,approximately%2072%20billion%20U.S.%20dollars>.
- Dan Strumpf. U.S. Judge orders China's ZTE to two more years of monitoring. *WSJ*, Oct 2018. URL <https://www.wsj.com/articles/u-s-judge-orders-chinas-zte-to-two-more-years-of-monitoring-1538634469>.
- Dan Strumpf and Katy Stech Ferek. U.S. tightens restrictions on Huawei's access to chips. *WSJ*, August 2020. URL <https://www.wsj.com/articles/commerce-department-tightens-restrictions-on-huaweis-access-to-chips-11597671747>.
- Tencent Holdings Limited. 2019 Tencent annual report. 2020a. URL <https://static.www.tencent.com/uploads/2020/04/02/ed18b0a8465d8bb733e338a1abe76b73.pdf>.

- Tencent Holdings Limited. 2020 Tencent interim report. 2020b. URL <https://cdc-tencent-com-1258344706.image.myqcloud.com/uploads/2020/08/26/c798476aba9e18d44d9179e103a2e07f.pdf>.
- The Communist Party of China Central Committee. The Communist Party of China Central Committee on upholding and improving the socialist system with Chinese characteristics decided to promote a number of major issues of national governance systems and governance modernization, november 2019. URL http://www.xinhuanet.com/2019-11/05/c_1125195786.htm.
- Peter Thompson. Patent citations and the geography of knowledge spillovers: Evidence from inventor-and examiner-added citations. *The Review of Economics and Statistics*, 88(2):383–388, 2006.
- Manuel Trajtenberg, Rebecca Henderson, and Adam Jaffe. University versus corporate patents: A window on the basicness of invention. *Economics of Innovation and New Technology*, 5(1):19–50, 1997.
- USPTO. General information concerning patents, may 2015. URL <https://www.uspto.gov/patents-getting-started/general-information-concerning-patents>.
- USPTO. Patents pendency data December 2020, february 2021. URL <https://www.uspto.gov/dashboard/patents/pendency.html>.
- Bart Verspagen. Mapping technological trajectories as patent citation networks: A study on the history of fuel cell research. *Advances in Complex Systems*, 10(01):93–115, 2007.
- Xianwen Wang, Xi Zhang, and Shenmeng Xu. Patent co-citation networks of fortune 500 companies. *Scientometrics*, 88(3):761–770, 2011.
- Shiao-Chun Wu and Hung-Yi Chen. Recognizing the core technology capabilities for companies through patent co-citations. In *2007 IEEE International Conference on Industrial Engineering and Engineering Management*, pages 2081–2085. IEEE, 2007.

Ming Zeng. Alibaba and the future of business. *Harvard Business Review*, august 2018.

URL <https://hbr.org/2018/09/alibaba-and-the-future-of-business>.

CHAPTER 9
APPENDIX

Figure 9.1: Patent Citation Network (1989-1997)

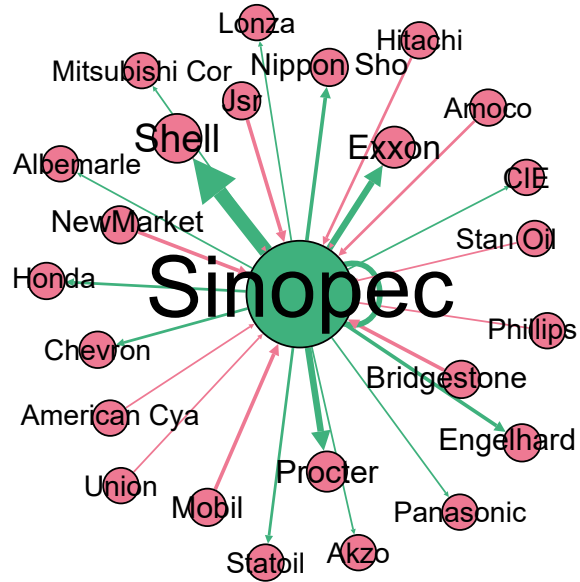


Figure 9.2: Patent Citation Network (1998)

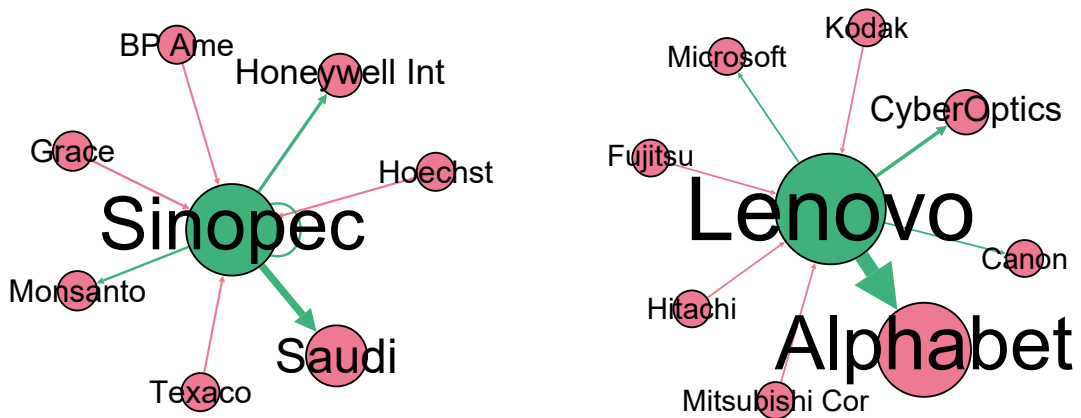


Figure 9.3: Patent Citation Network (1999)

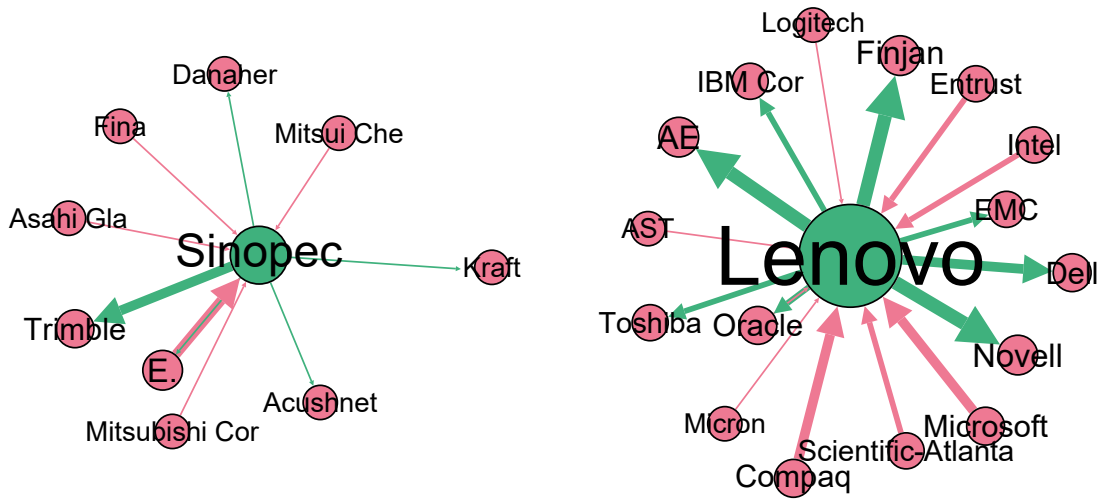


Figure 9.4: Patent Citation Network (2000)

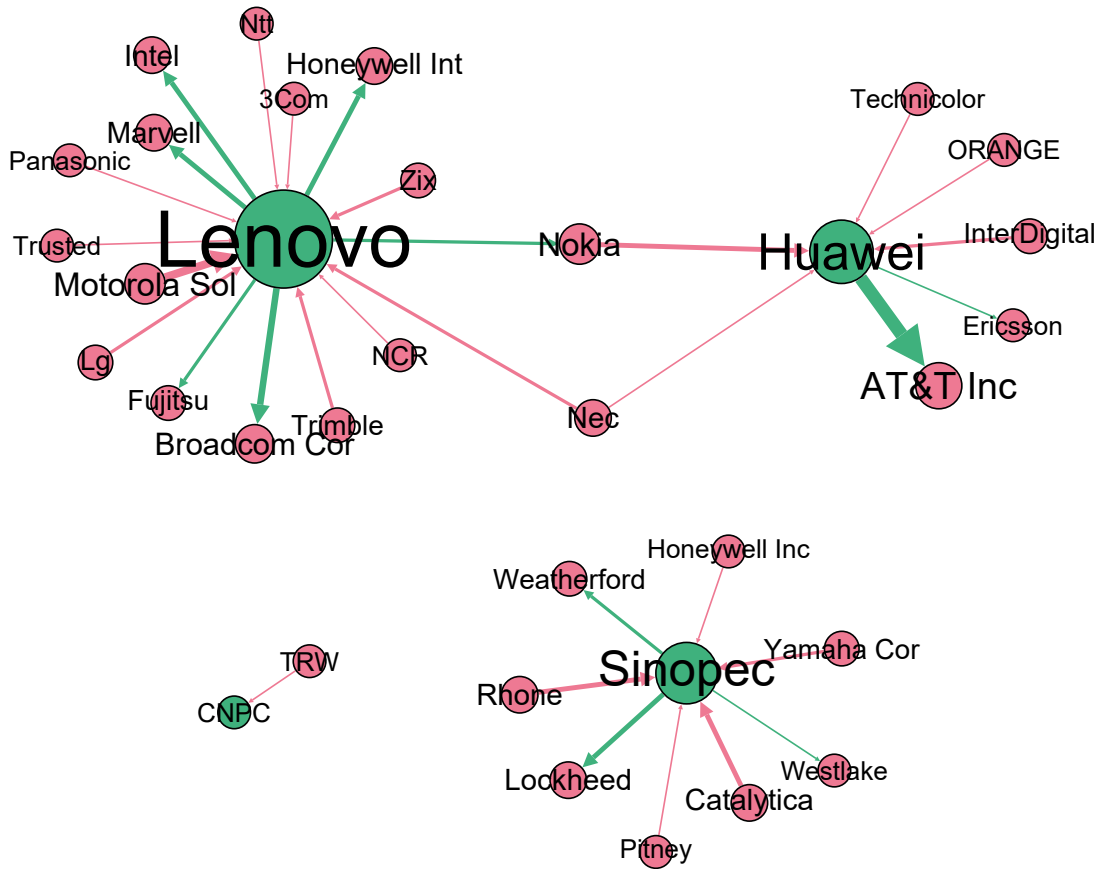


Figure 9.5: Patent Citation Network (2001)

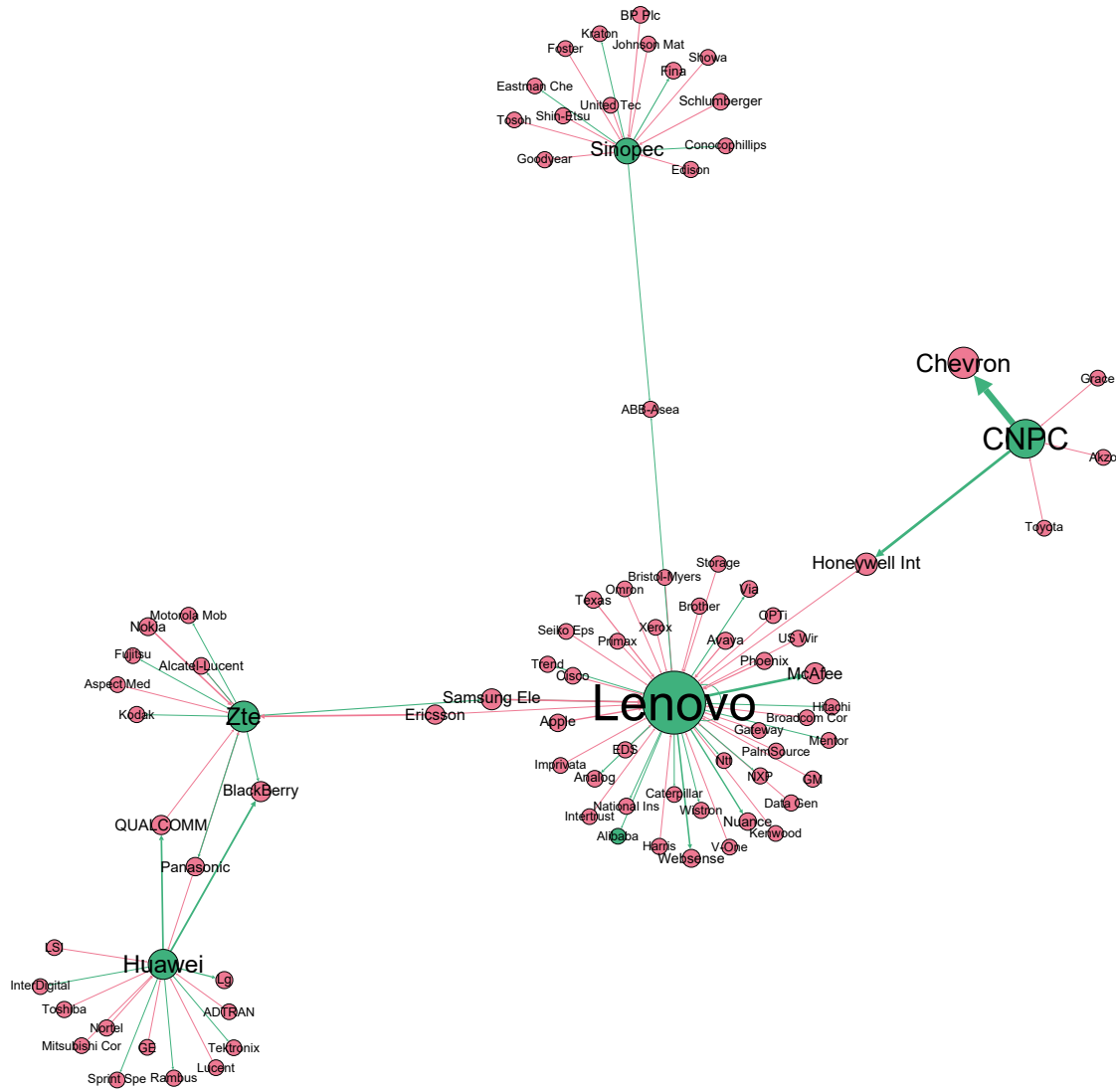


Figure 9.8: Patent Citation Network (2004)

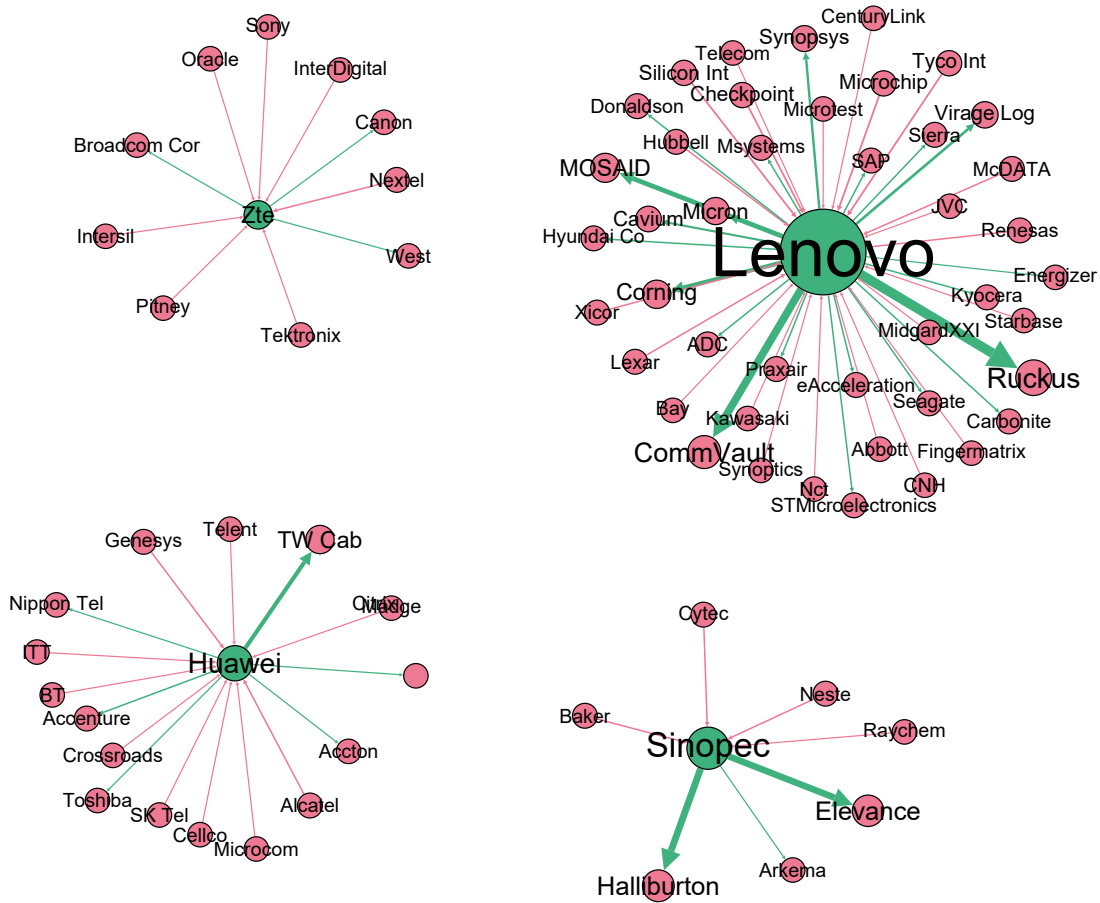


Figure 9.9: Patent Citation Network (2005)

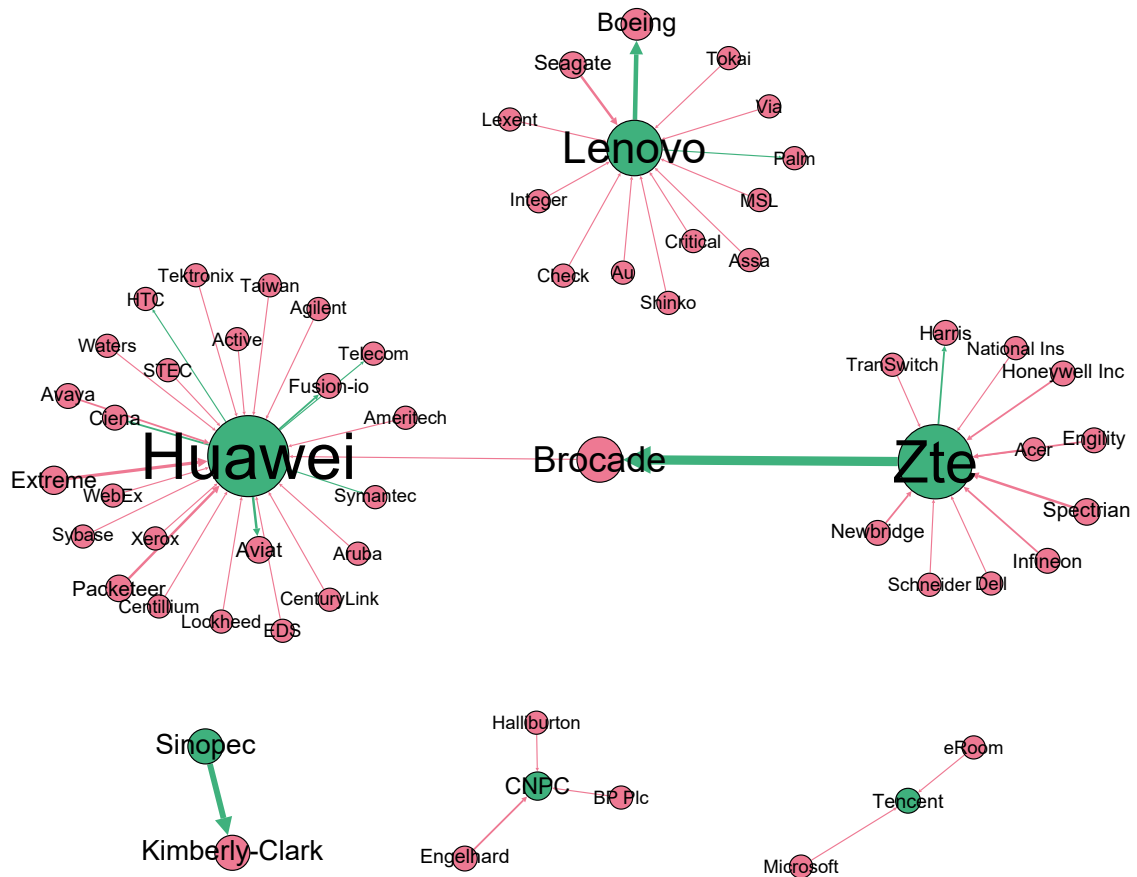


Figure 9.10: Patent Citation Network (2006)

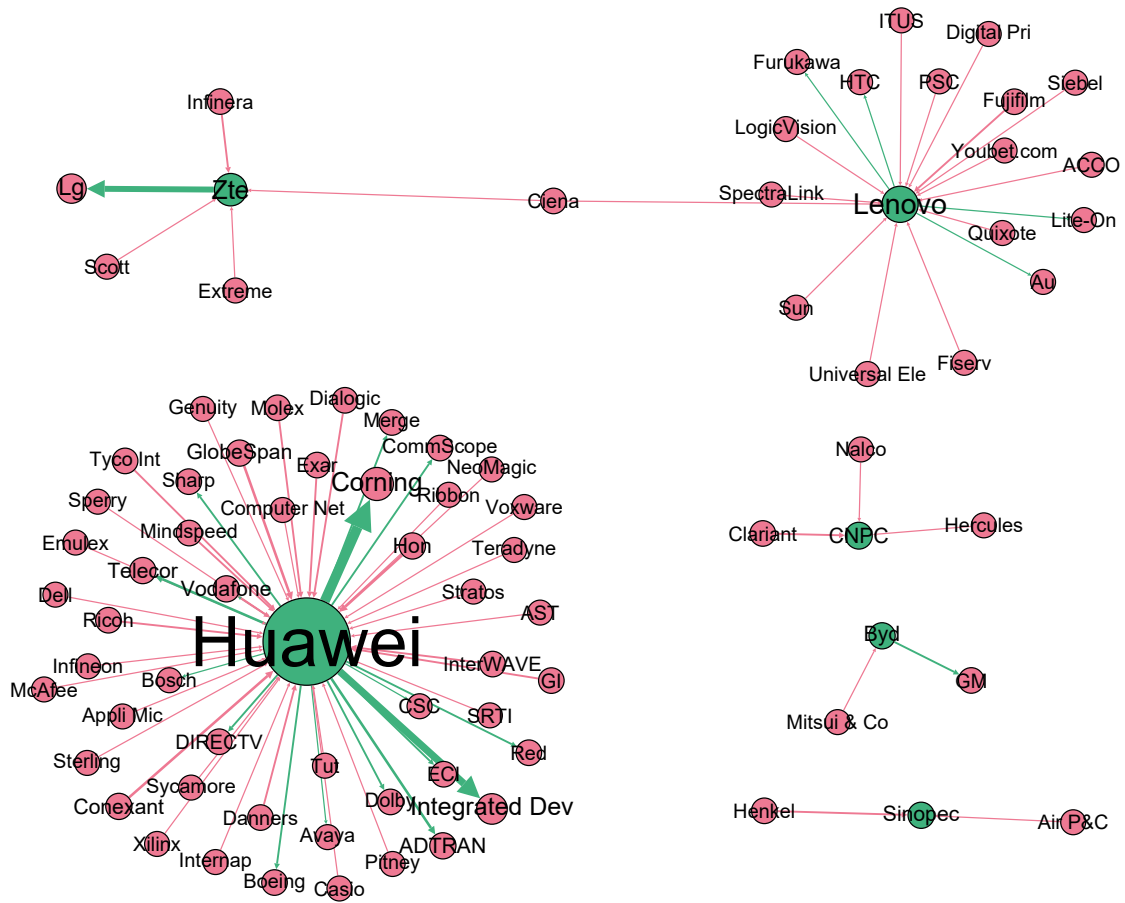


Figure 9.12: Patent Citation Network (2008)

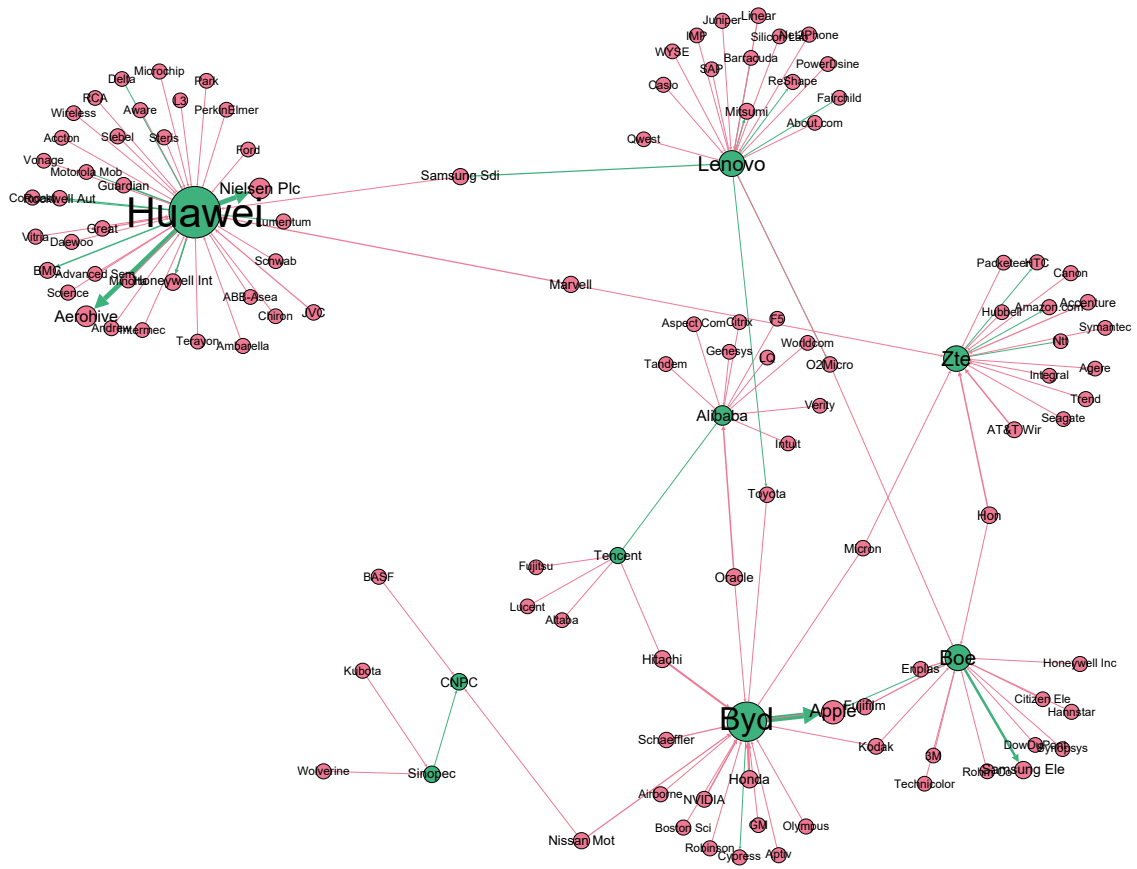


Figure 9.13: Patent Citation Network (2009)

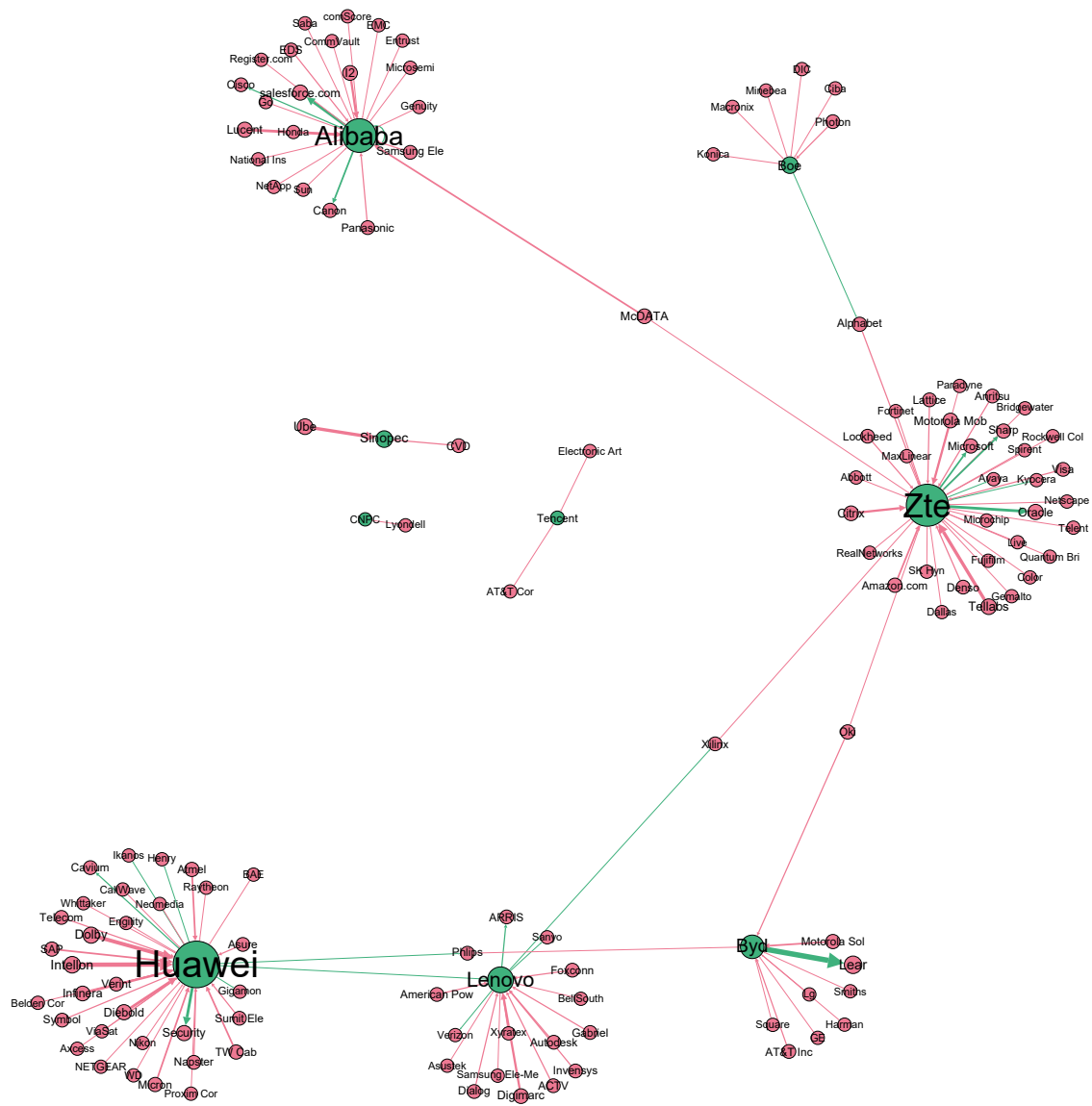


Figure 9.14: Patent Citation Network (2010)

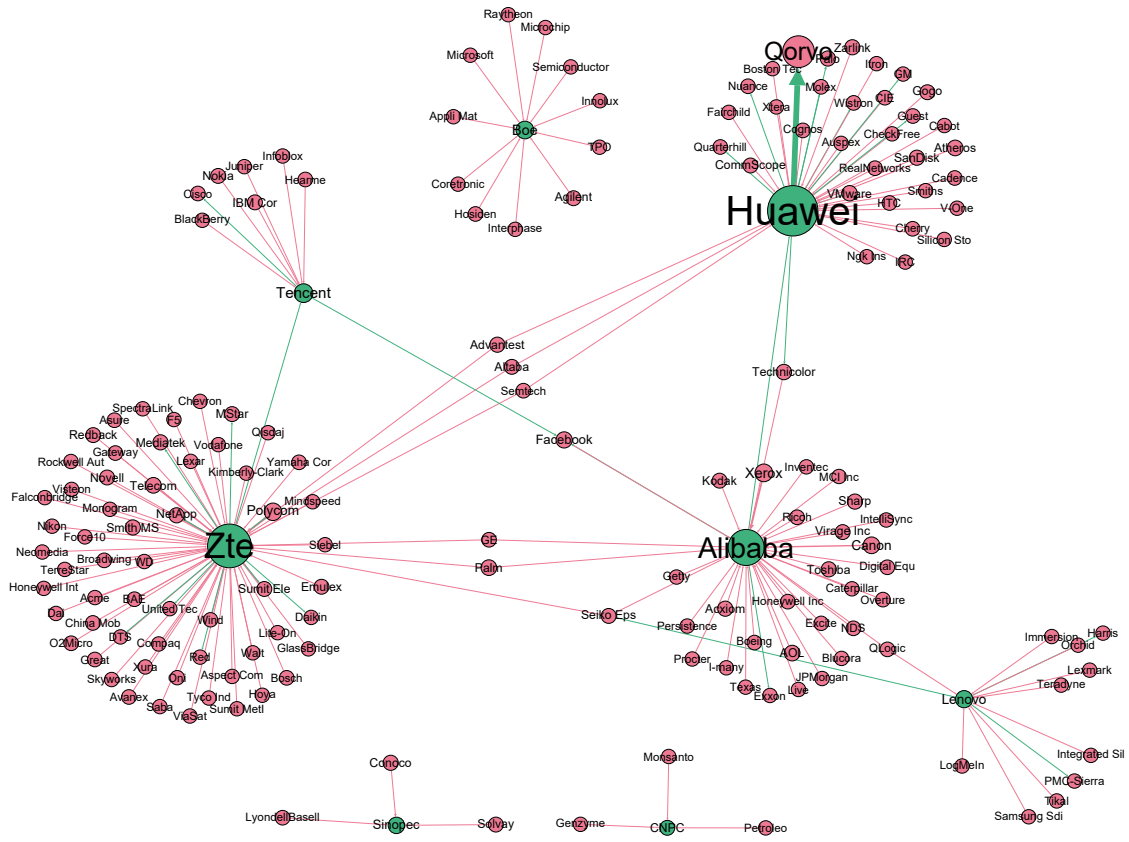


Figure 9.15: Patent Citation Network (2011)

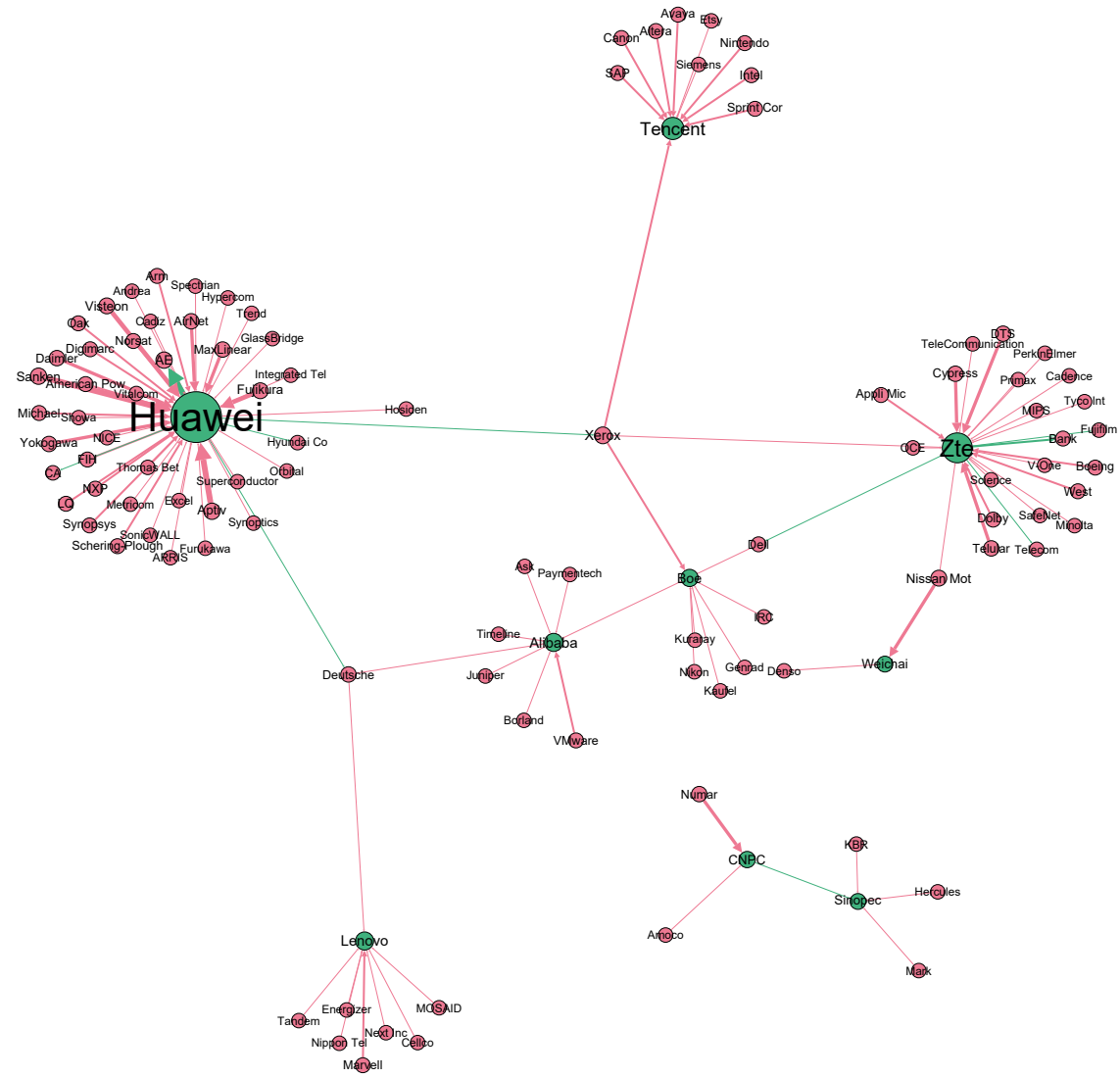


Figure 9.17: Patent Citation Network (2013)

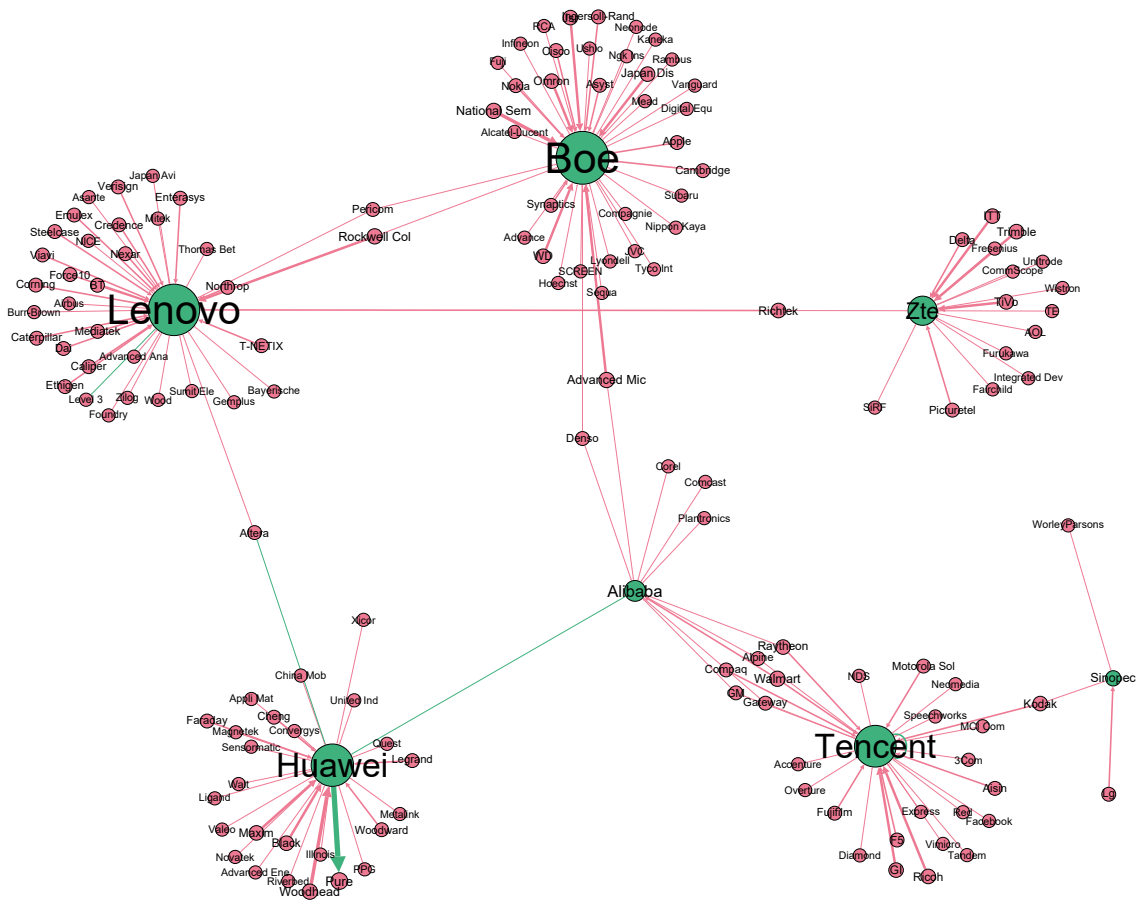


Figure 9.18: Bibliographic Coupling Network (1989-1997)

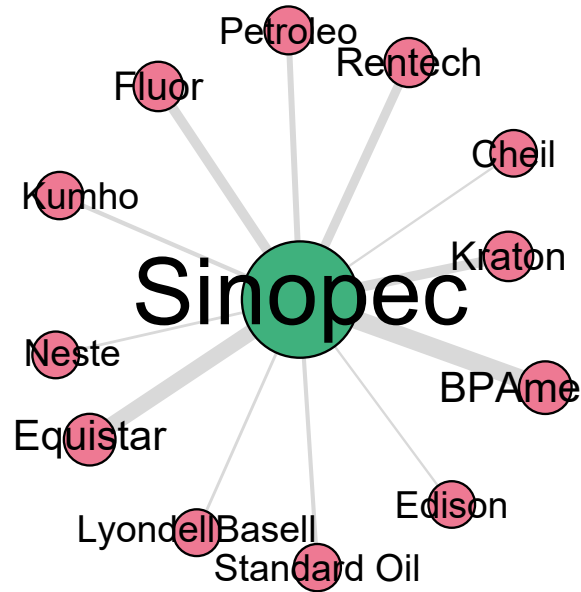


Figure 9.19: Bibliographic Coupling Network (1998)

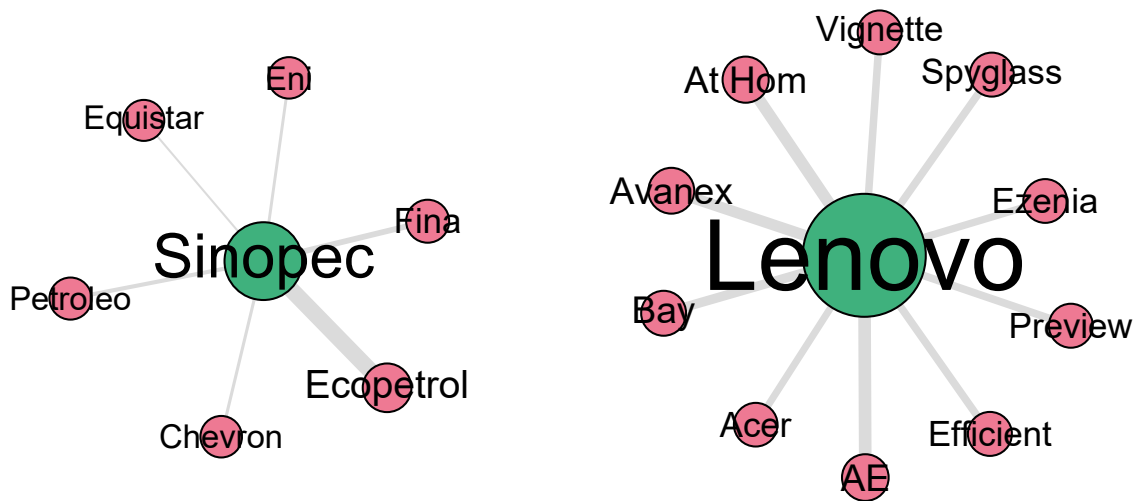


Figure 9.20: Bibliographic Coupling Network (1999)

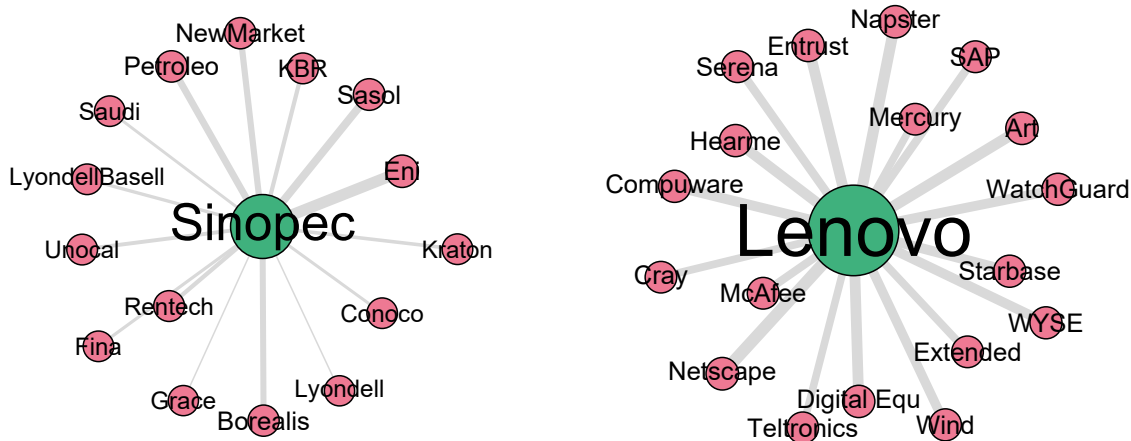


Figure 9.21: Bibliographic Coupling Network (2000)

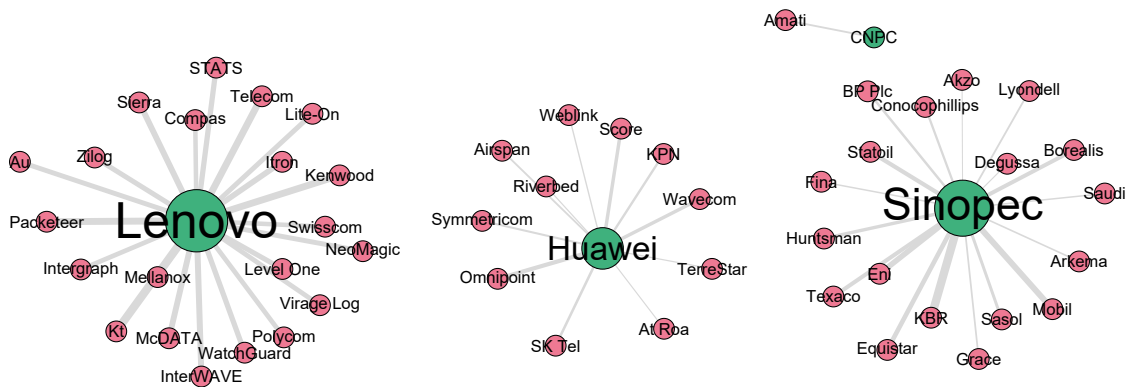


Figure 9.23: Bibliographic Coupling Network (2002)

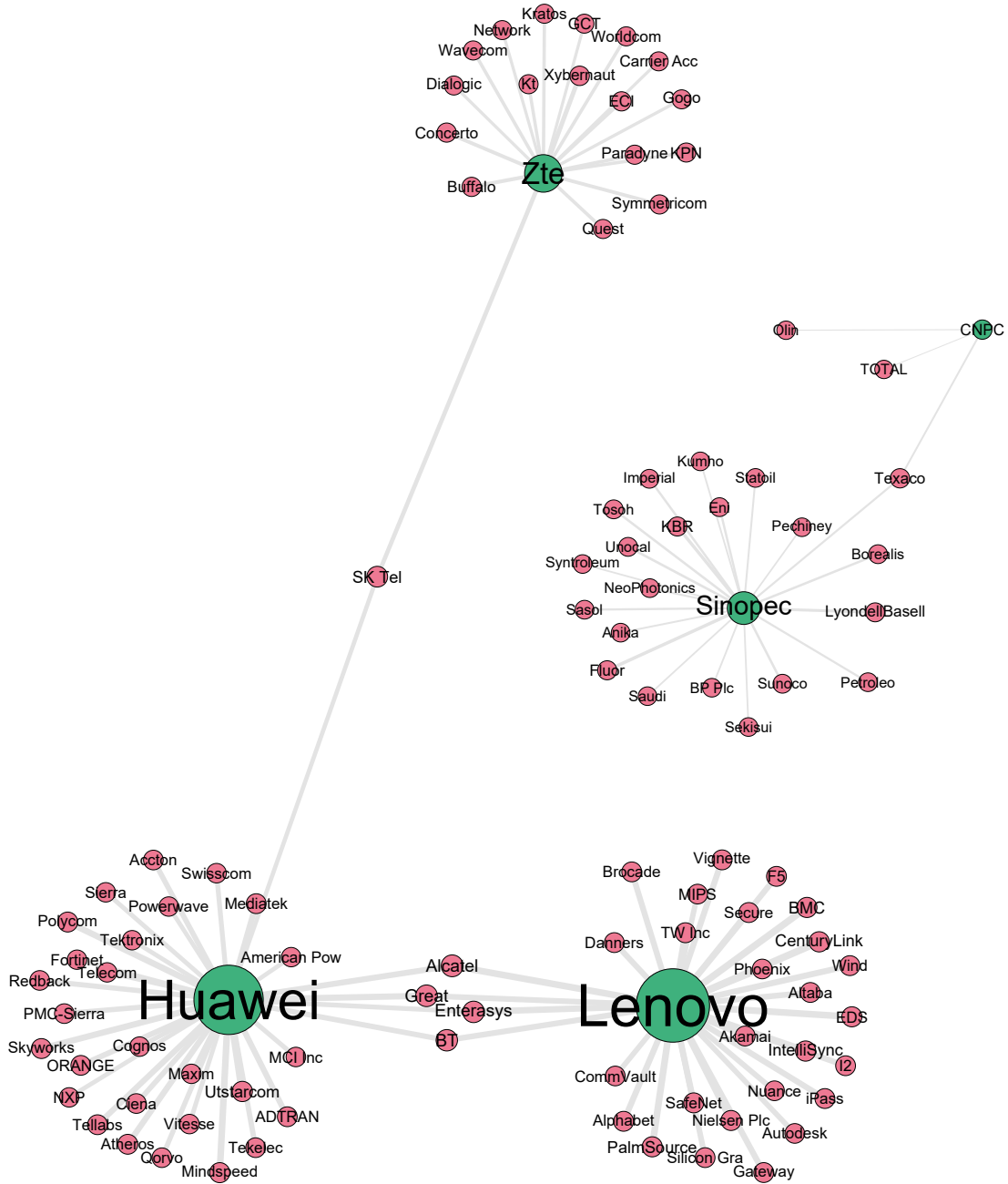


Figure 9.24: Bibliographic Coupling Network (2003)

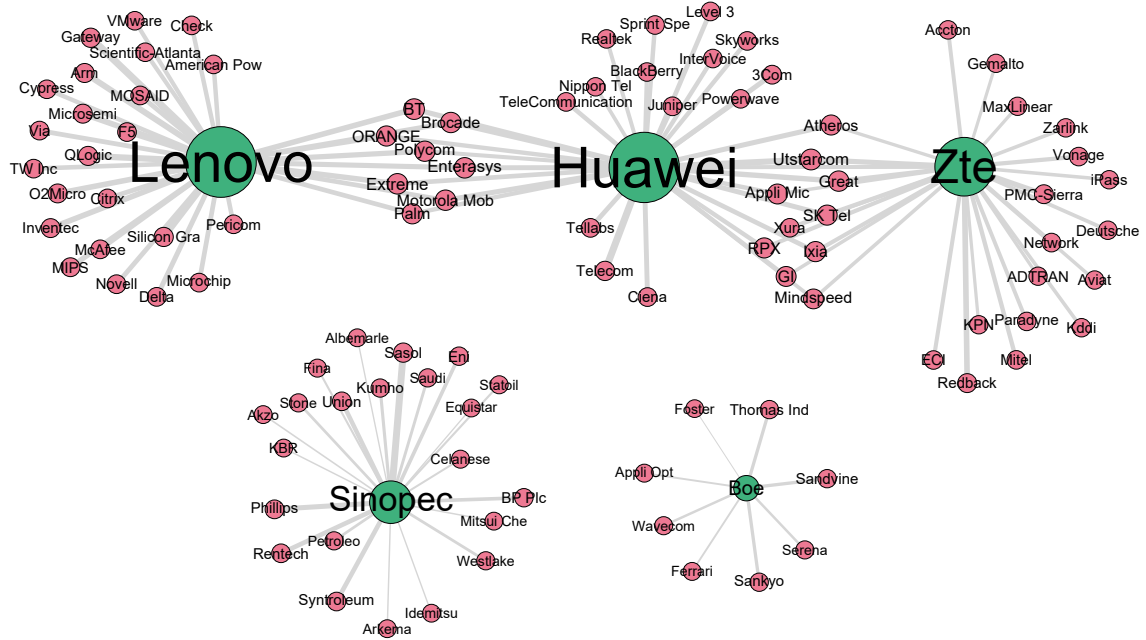


Figure 9.25: Bibliographic Coupling Network (2004)

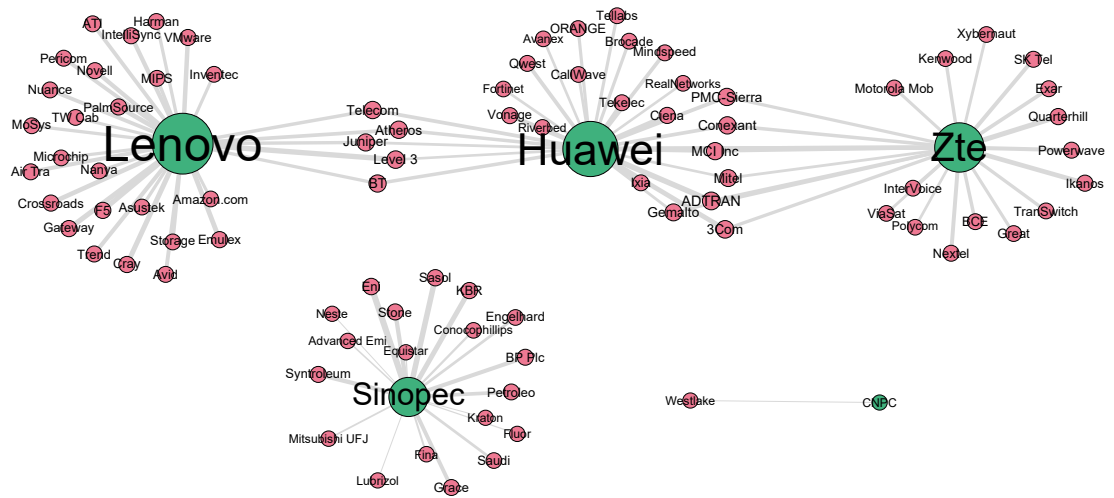


Figure 9.26: Bibliographic Coupling Network (2005)

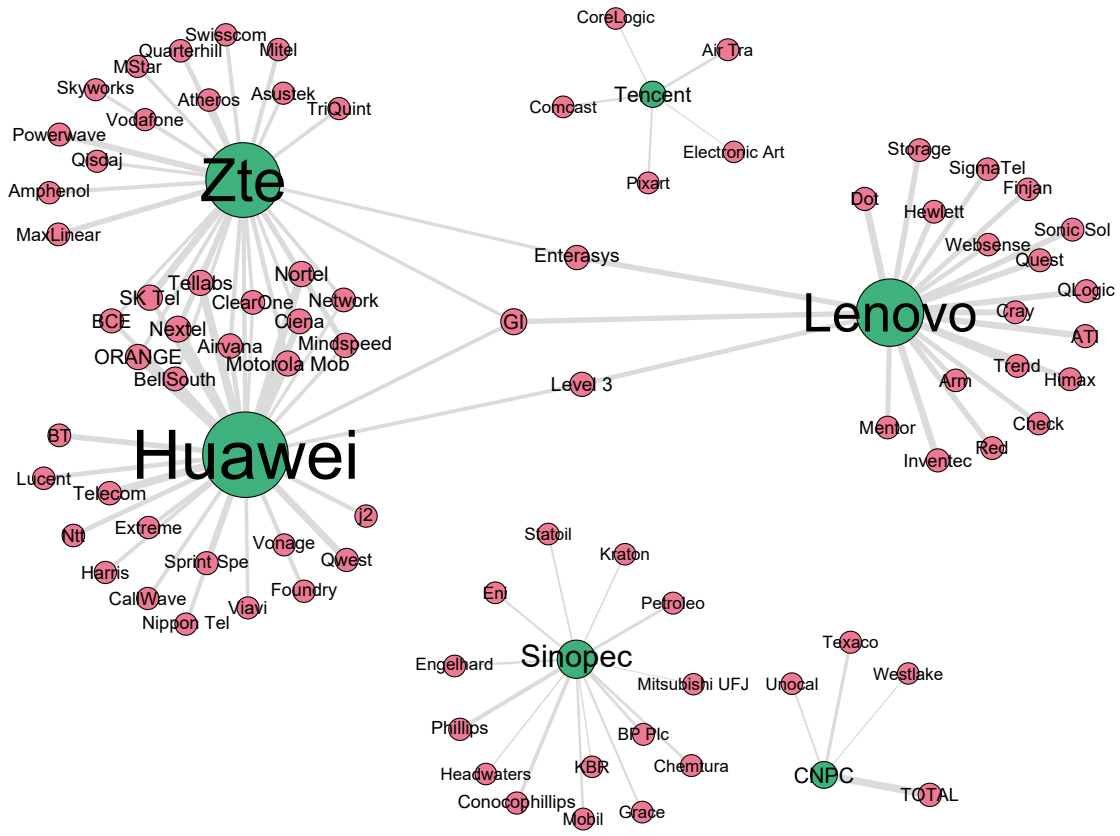


Figure 9.27: Bibliographic Coupling Network (2006)

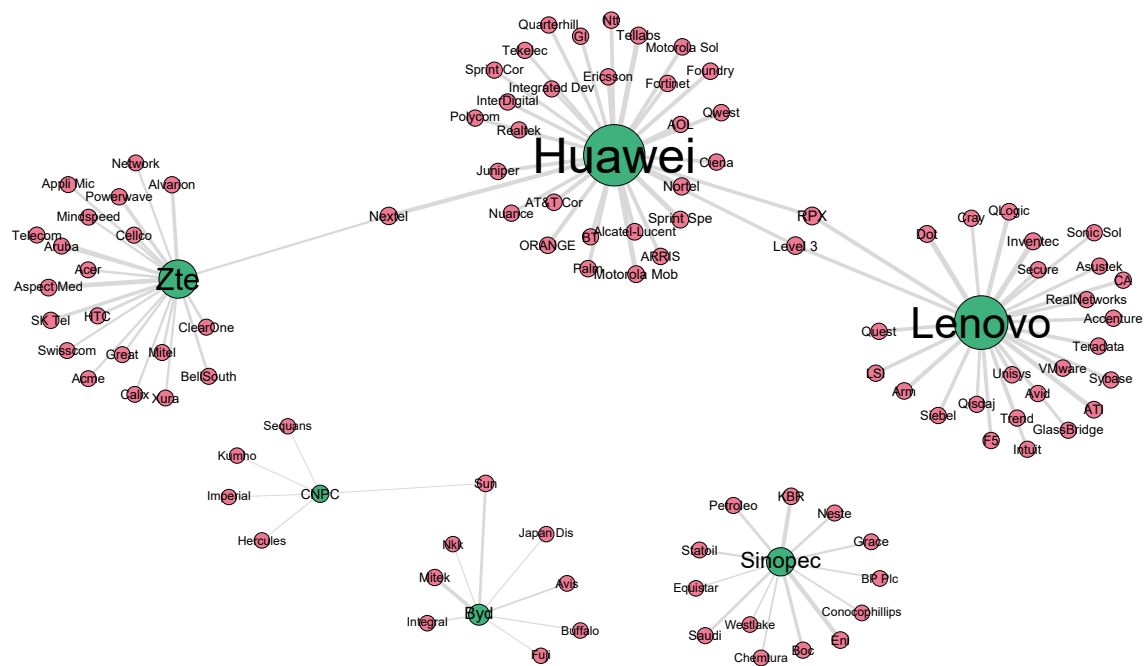


Figure 9.28: Bibliographic Coupling Network (2007)

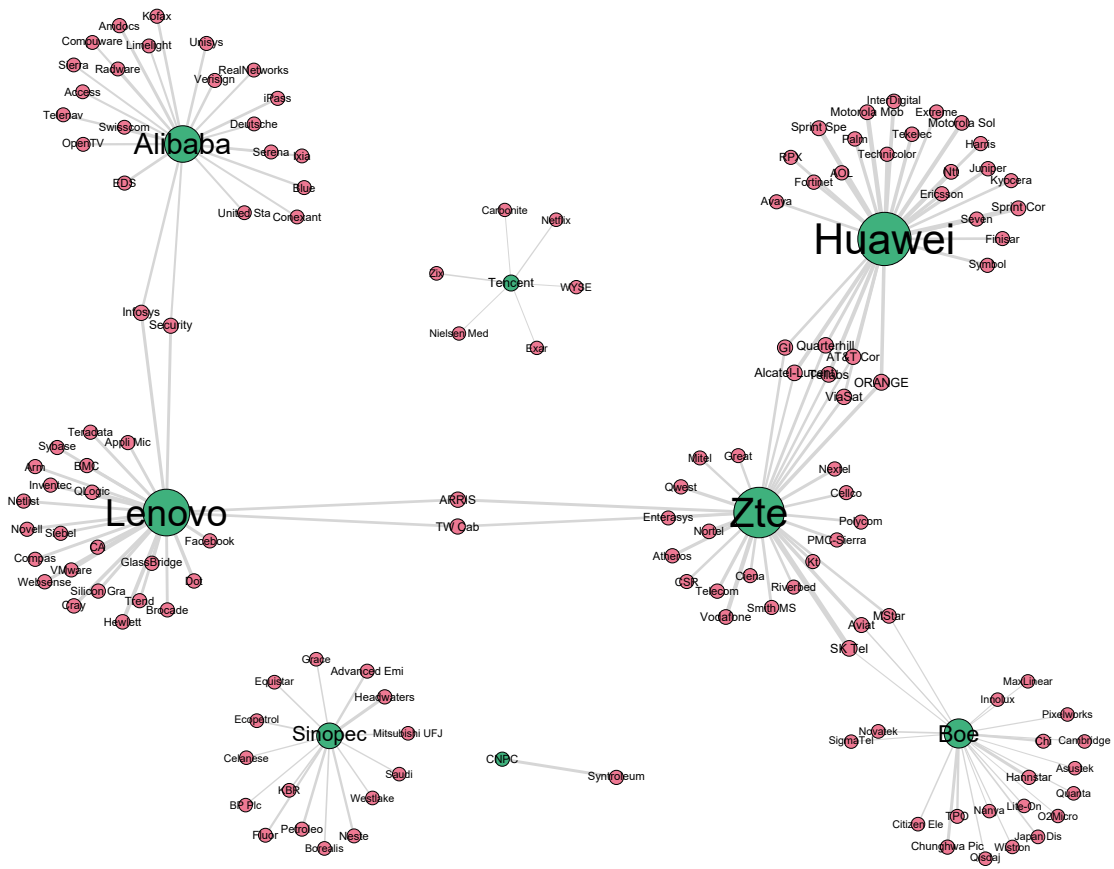


Figure 9.29: Bibliographic Coupling Network (2008)

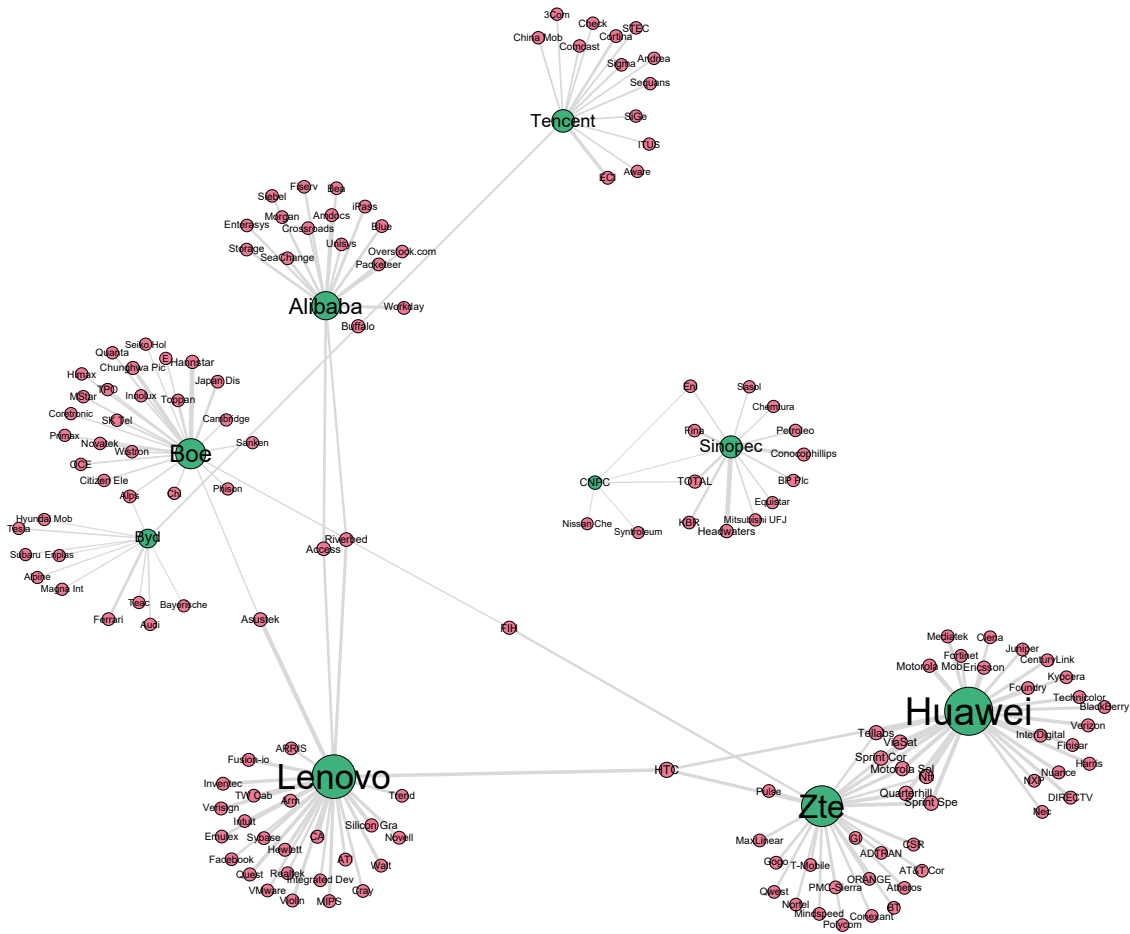


Figure 9.30: Bibliographic Coupling Network (2009)

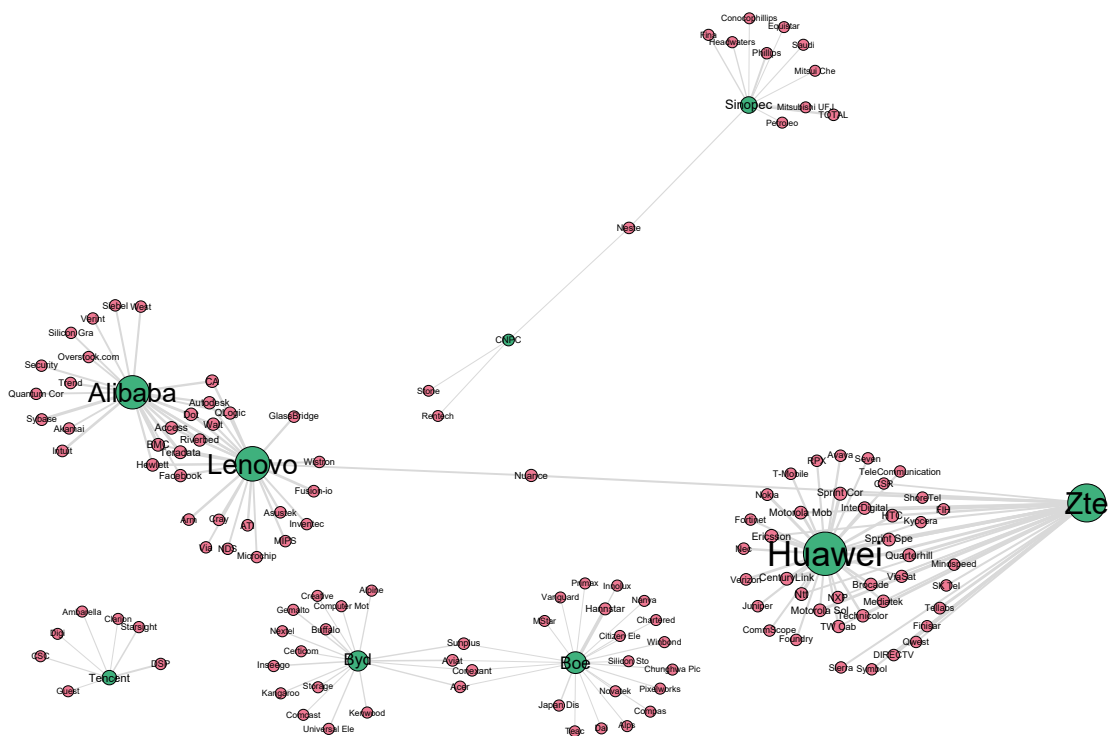


Figure 9.31: Bibliographic Coupling Network (2010)

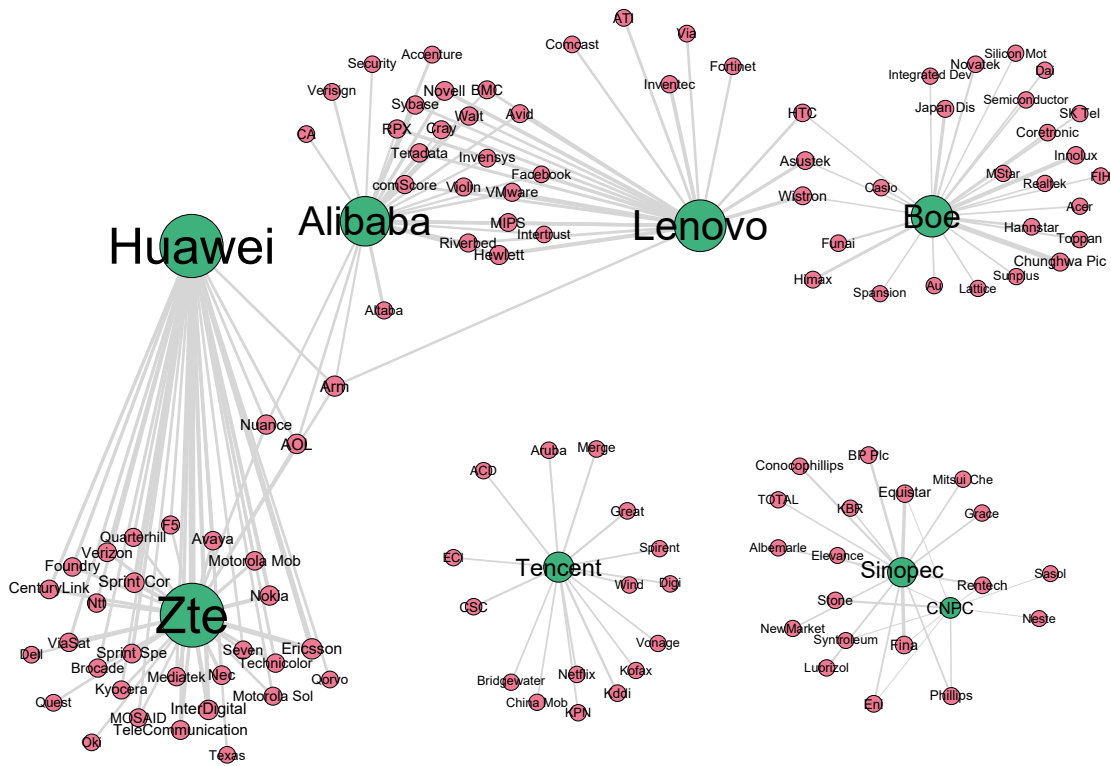


Figure 9.32: Bibliographic Coupling Network (2011)

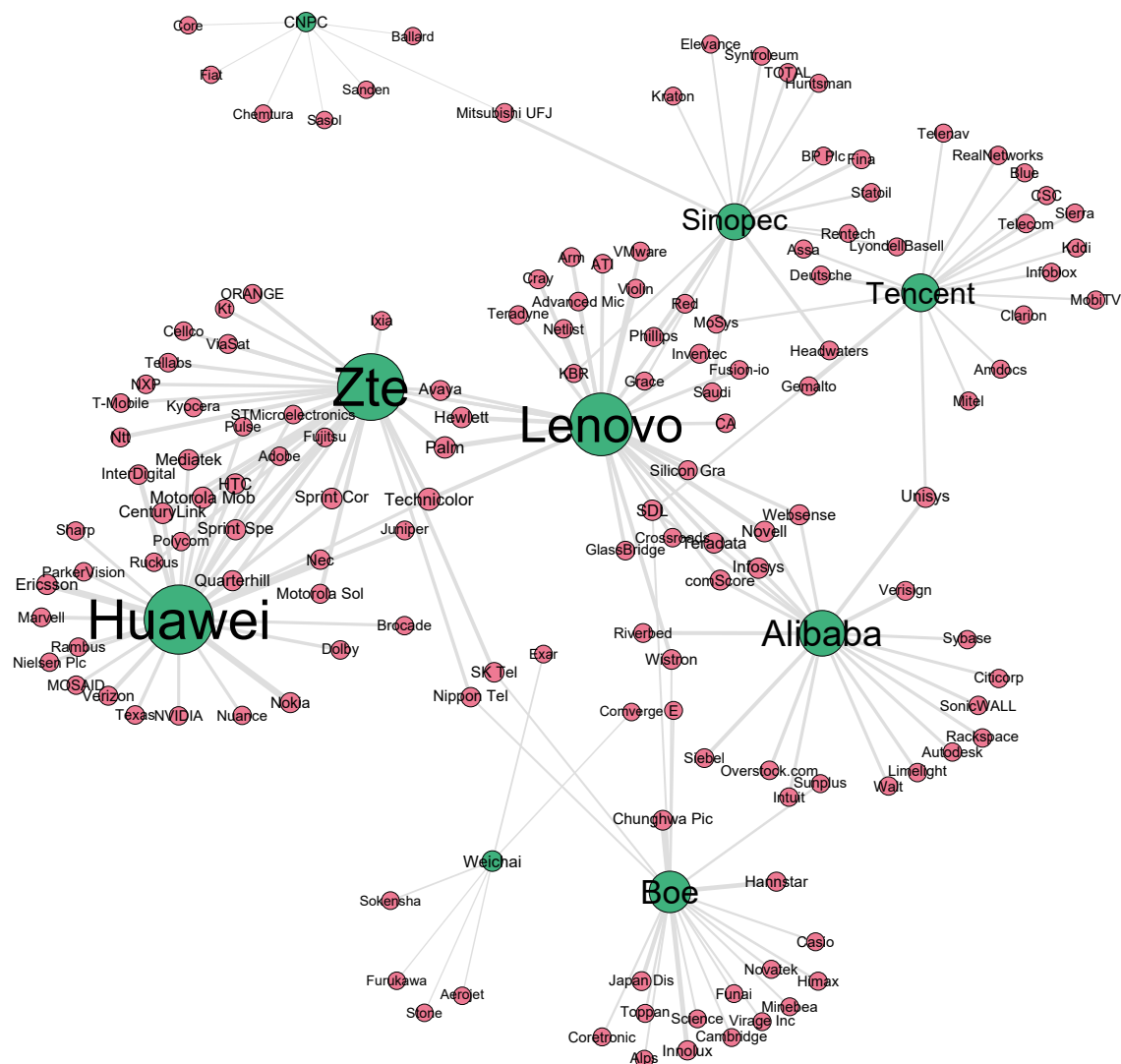


Figure 9.33: Bibliographic Coupling Network (2012)

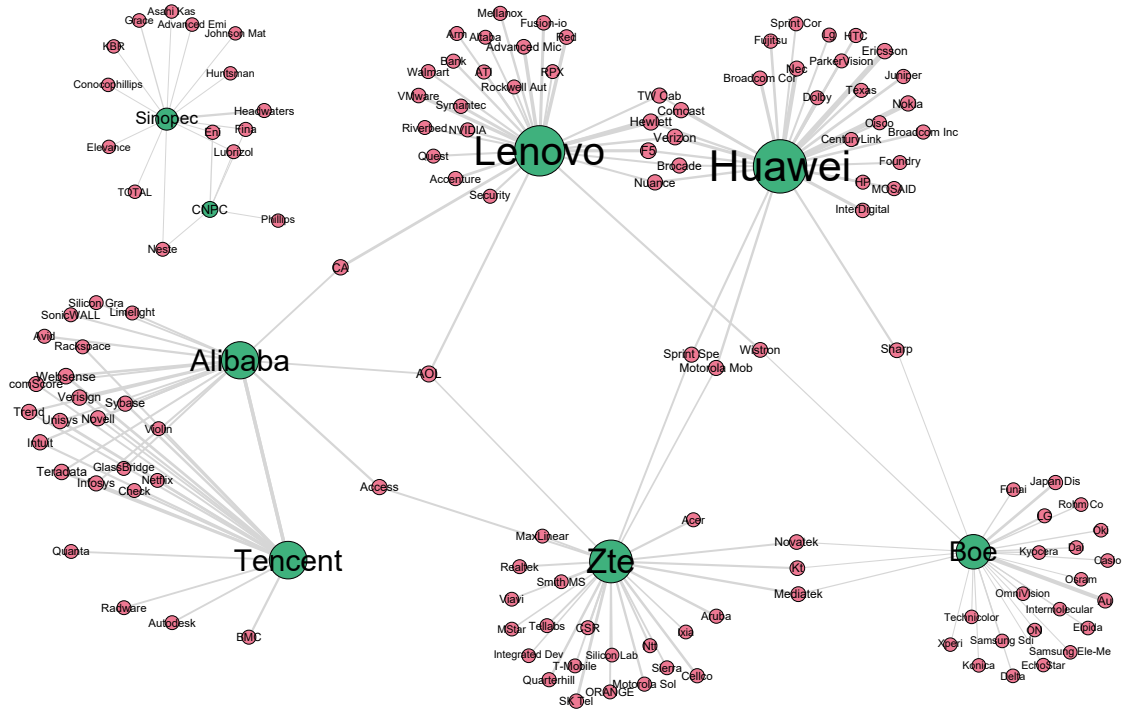


Figure 9.34: Bibliographic Coupling Network (2013)

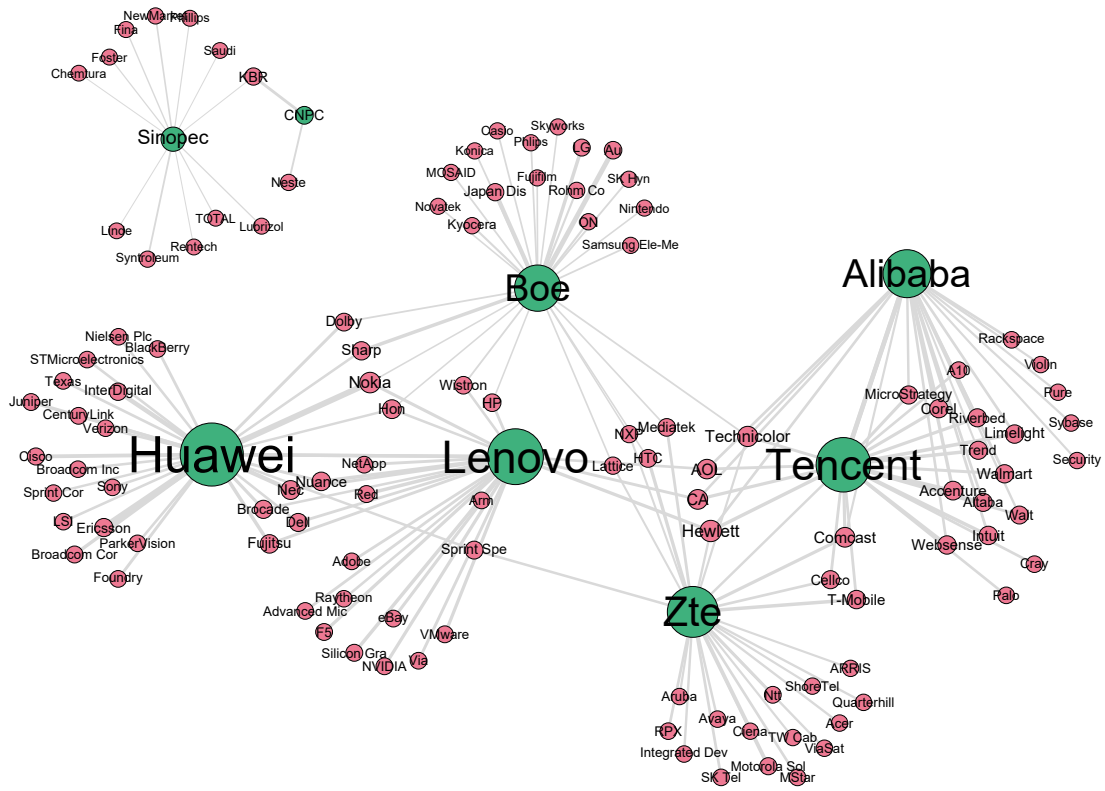


Figure 9.35: Mean Forward Citation–Zte and its Competitors (1)

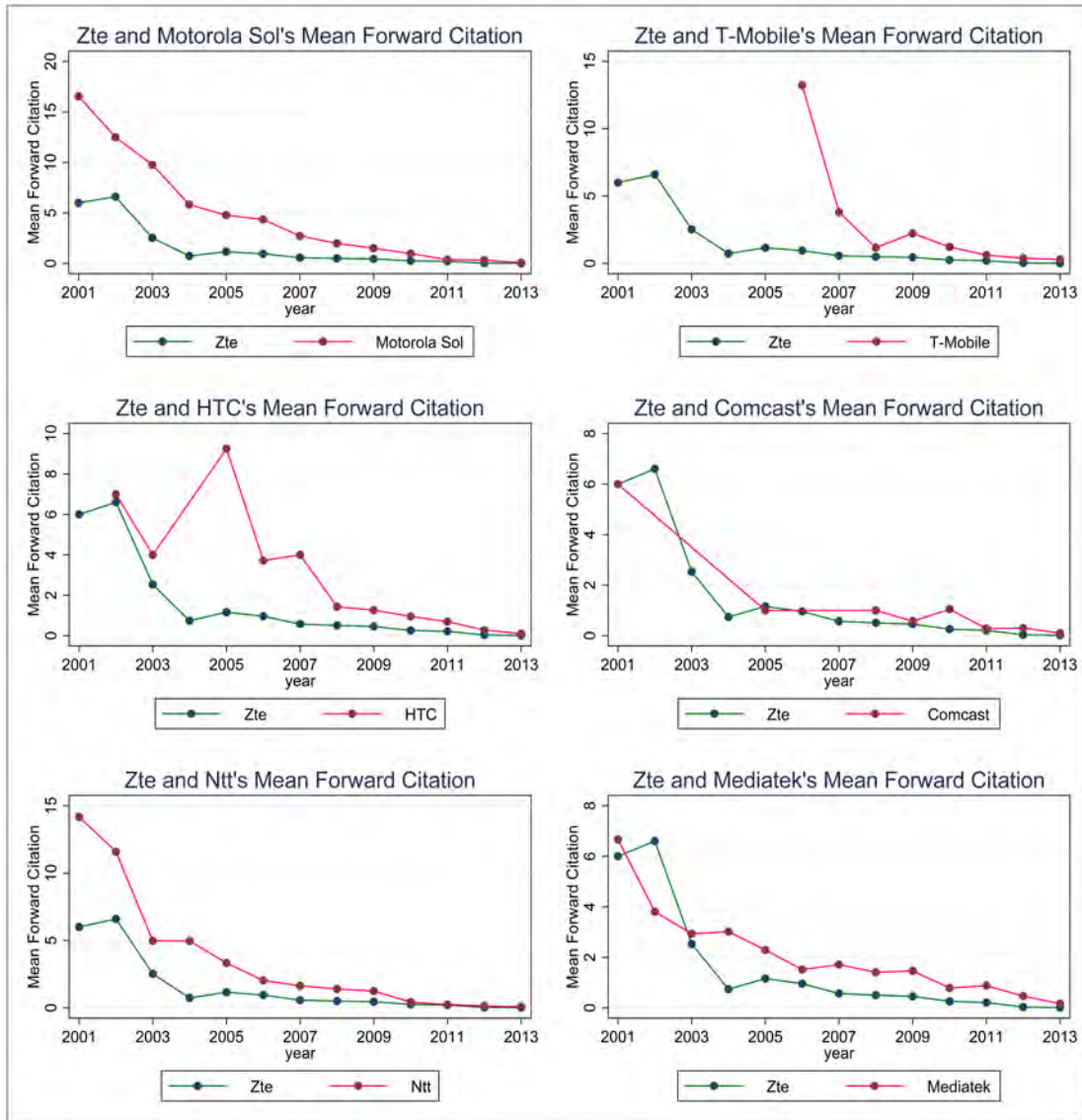


Figure 9.36: Mean Forward Citation–Zte and its Competitors (2)

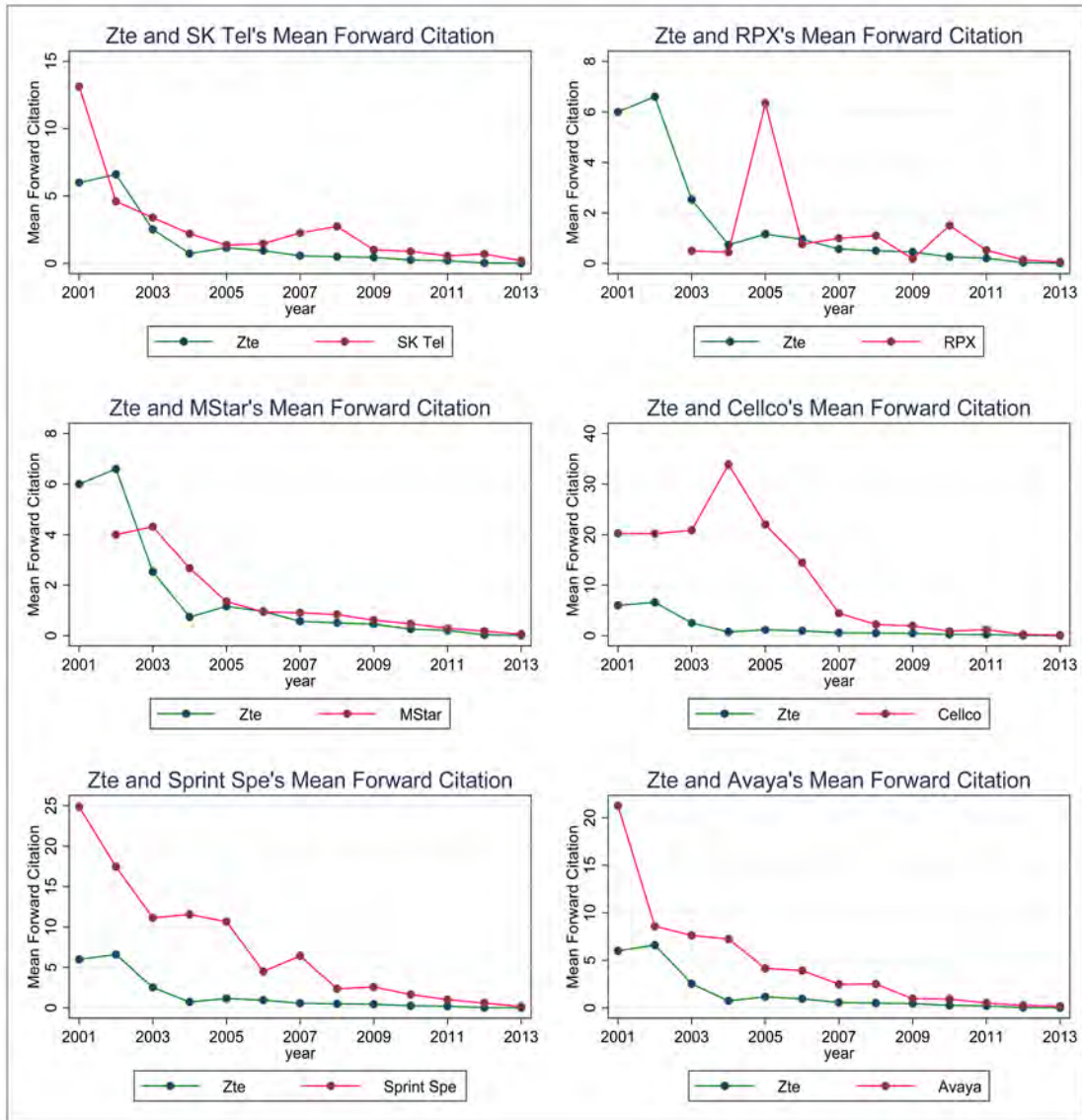


Figure 9.37: Mean Forward Citation–Boe and its Competitors (1)

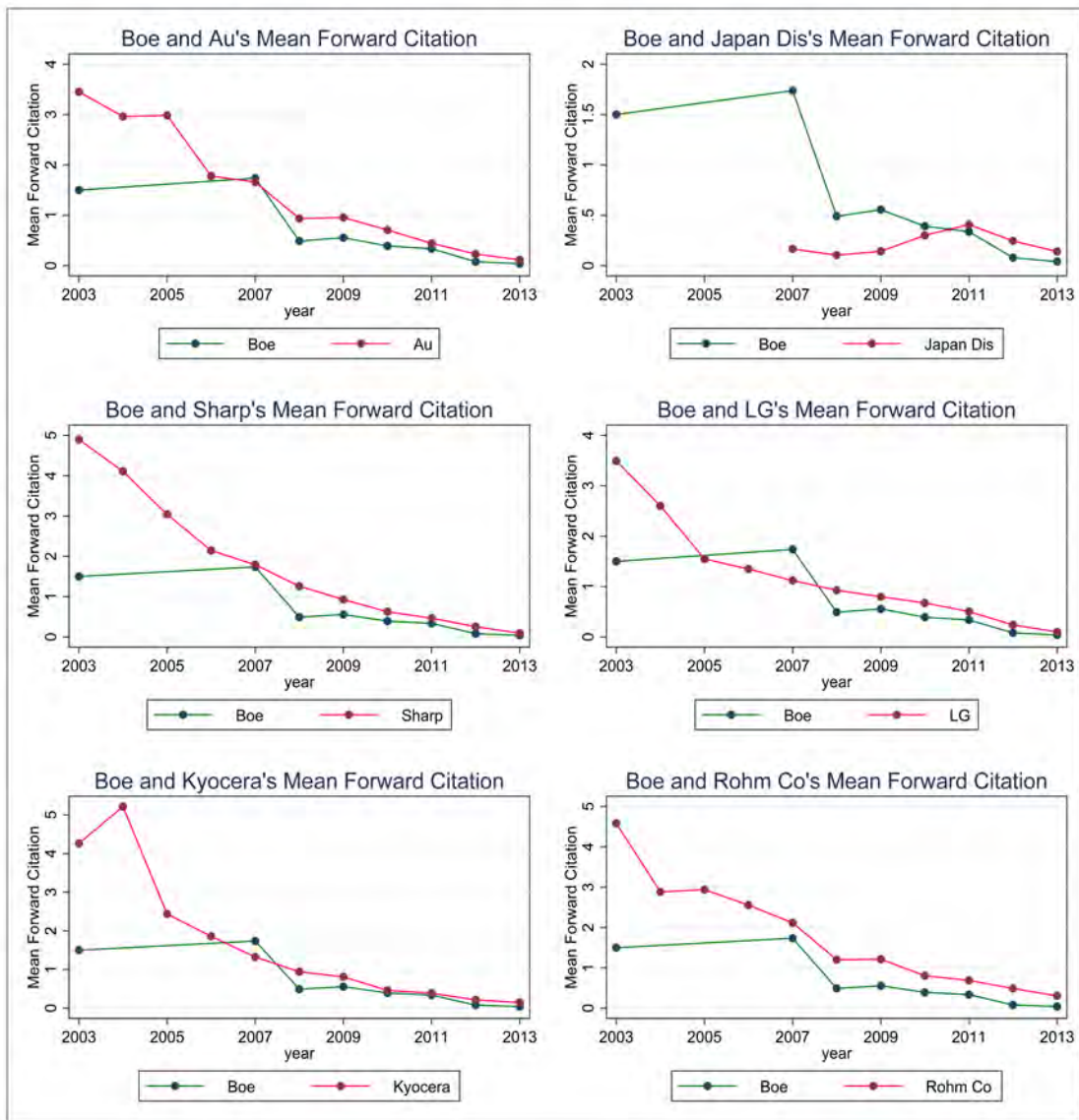


Figure 9.38: Mean Forward Citation–Boe and its Competitors (2)

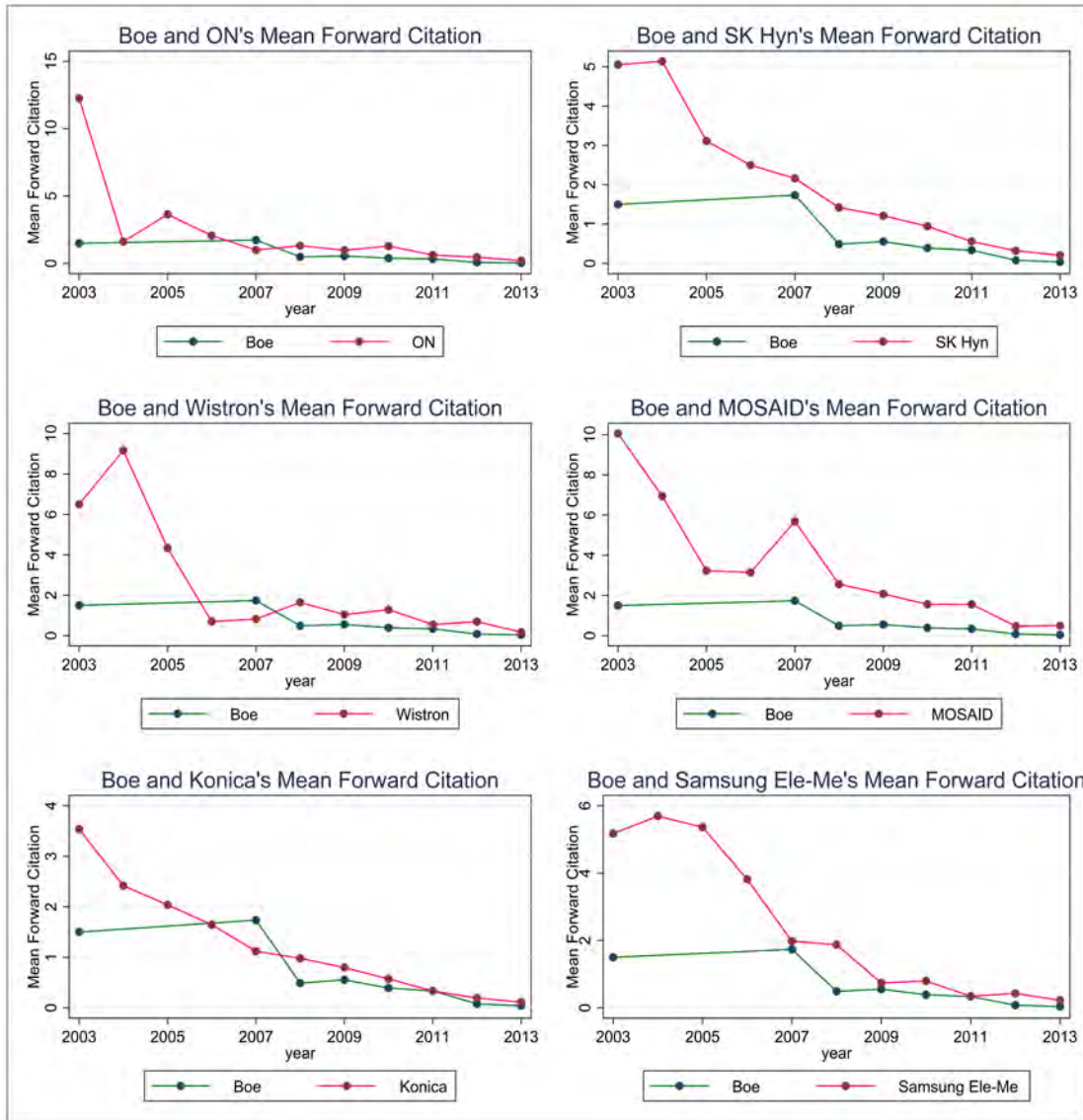


Figure 9.39: Mean Forward Citation–Lenovo and its Competitors (1)

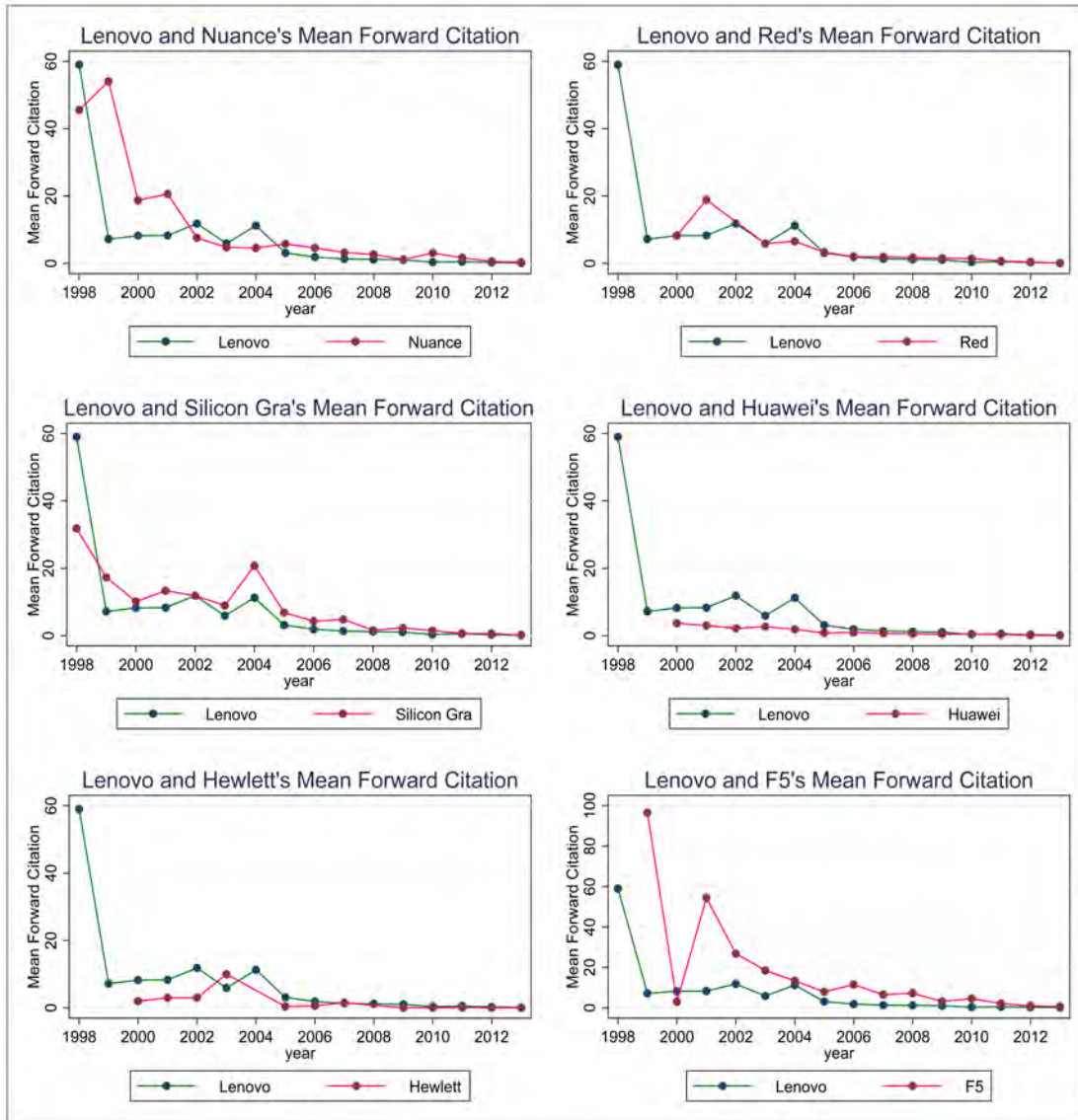


Figure 9.40: Mean Forward Citation–Lenovo and its Competitors (2)

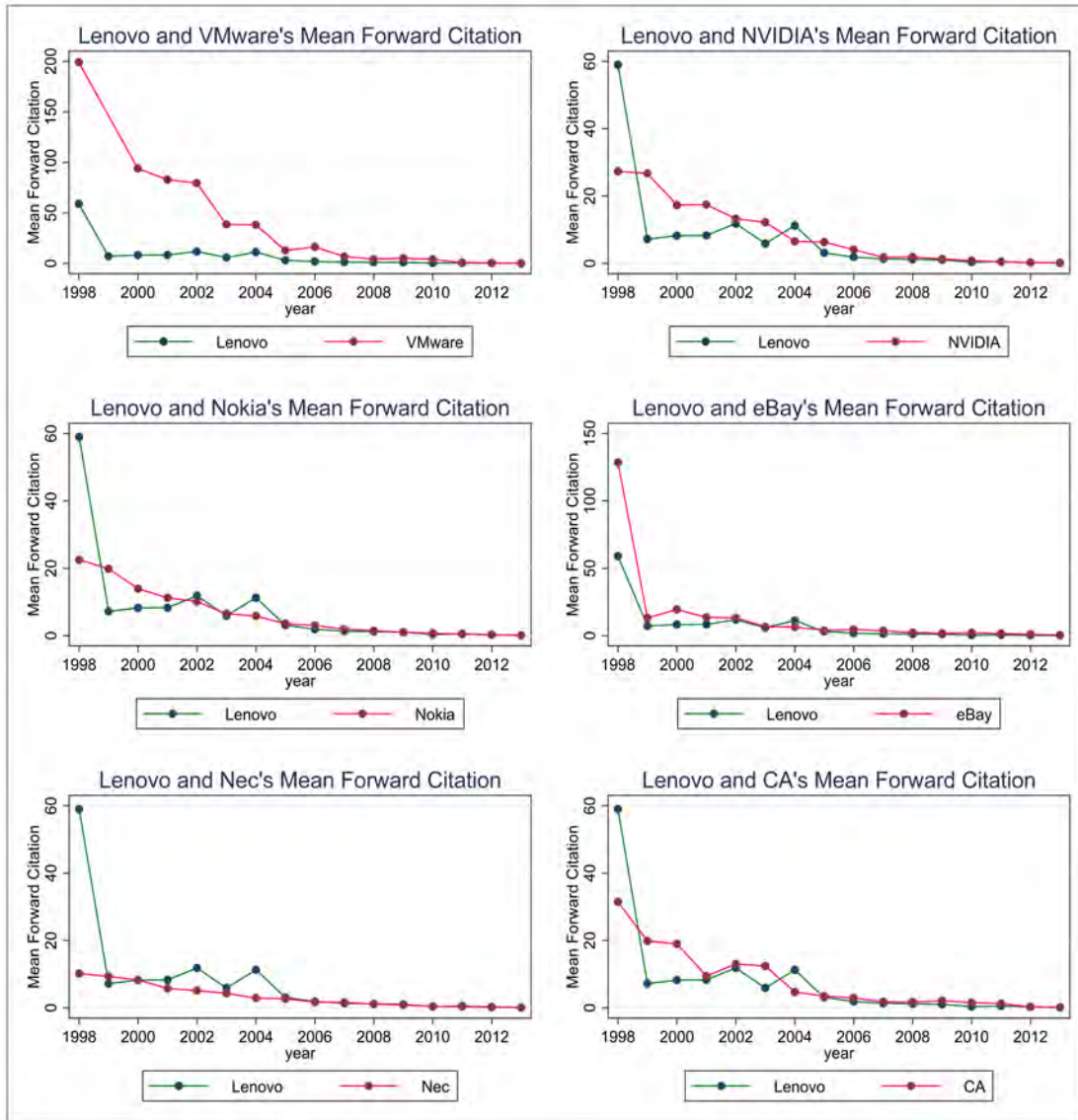


Figure 9.41: Mean Forward Citation–Sinopec and its Competitors (1)

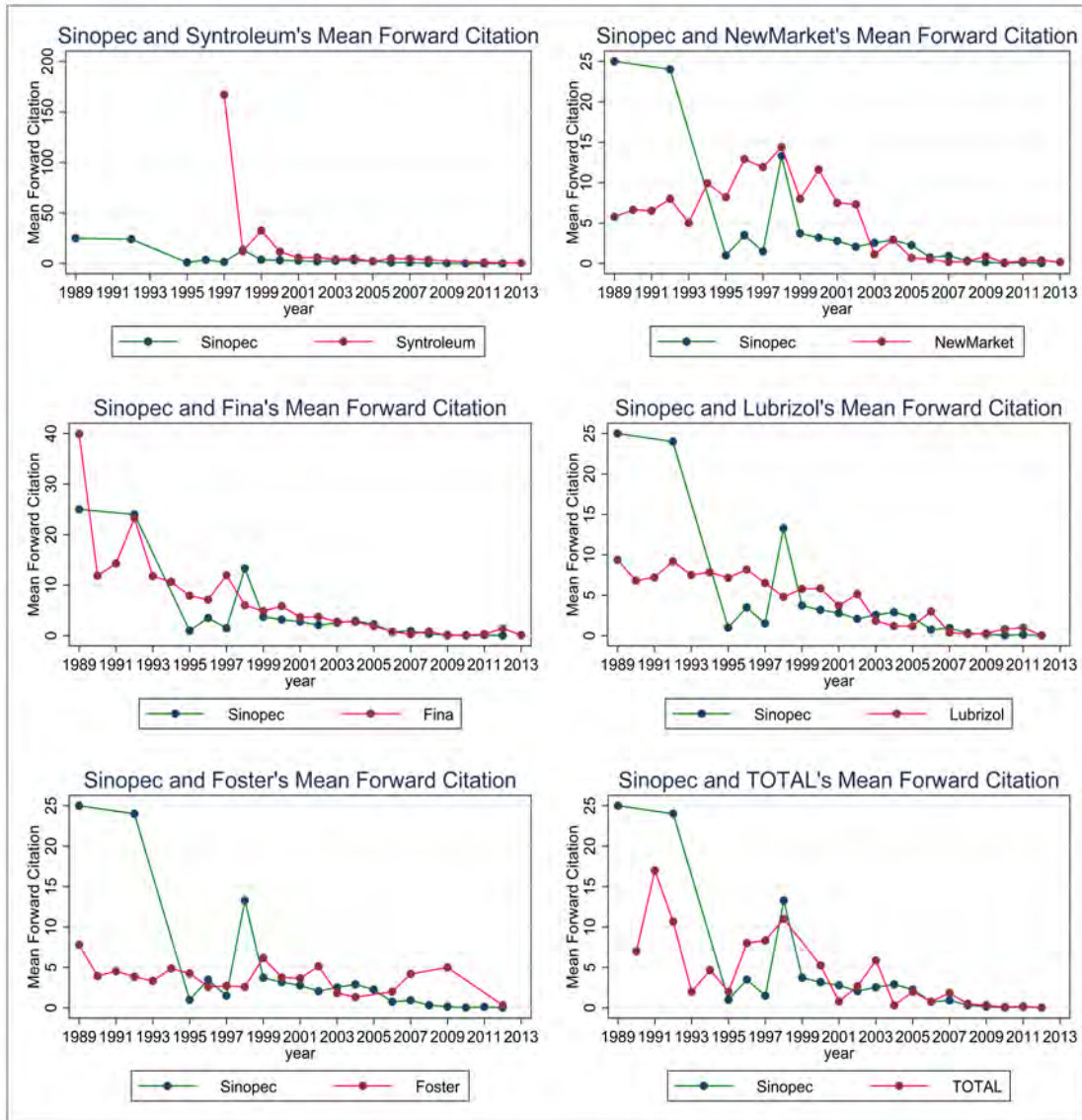


Figure 9.42: Mean Forward Citation–Sinopec and its Competitors (2)

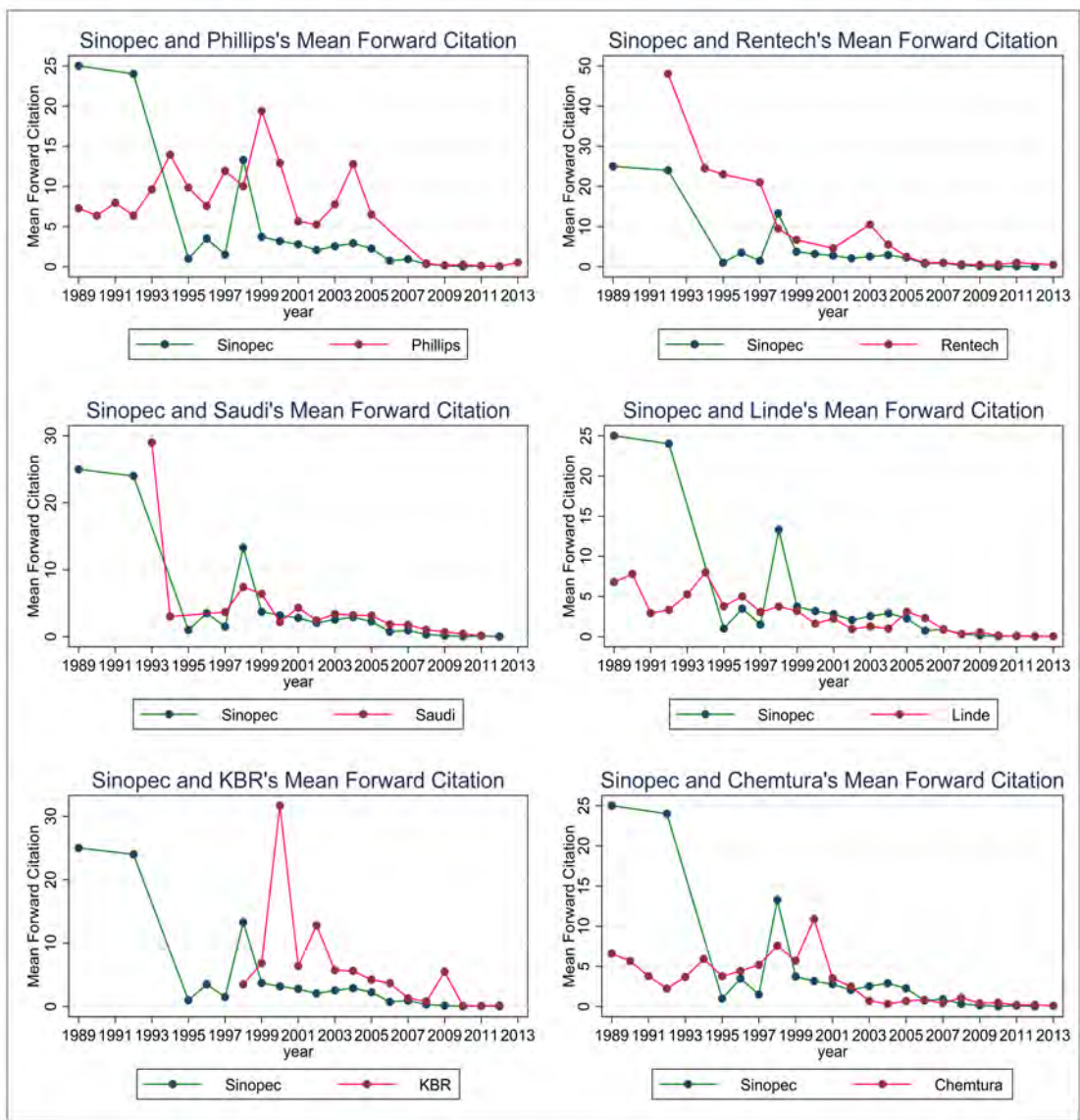


Figure 9.43: Mean Forward Citation–Tencent and its Competitors (1)

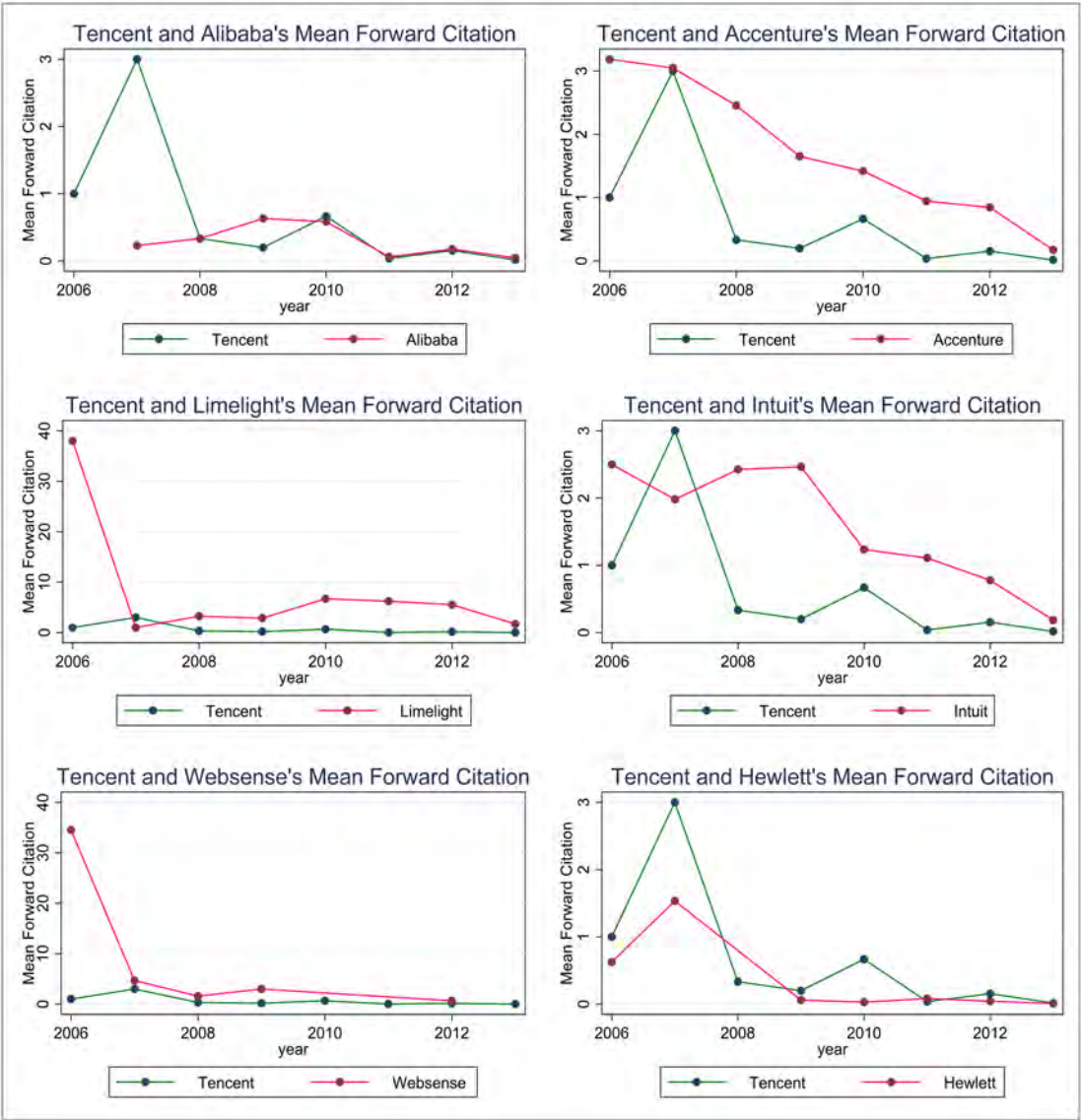


Figure 9.44: Mean Forward Citation–Tencent and its Competitors (2)

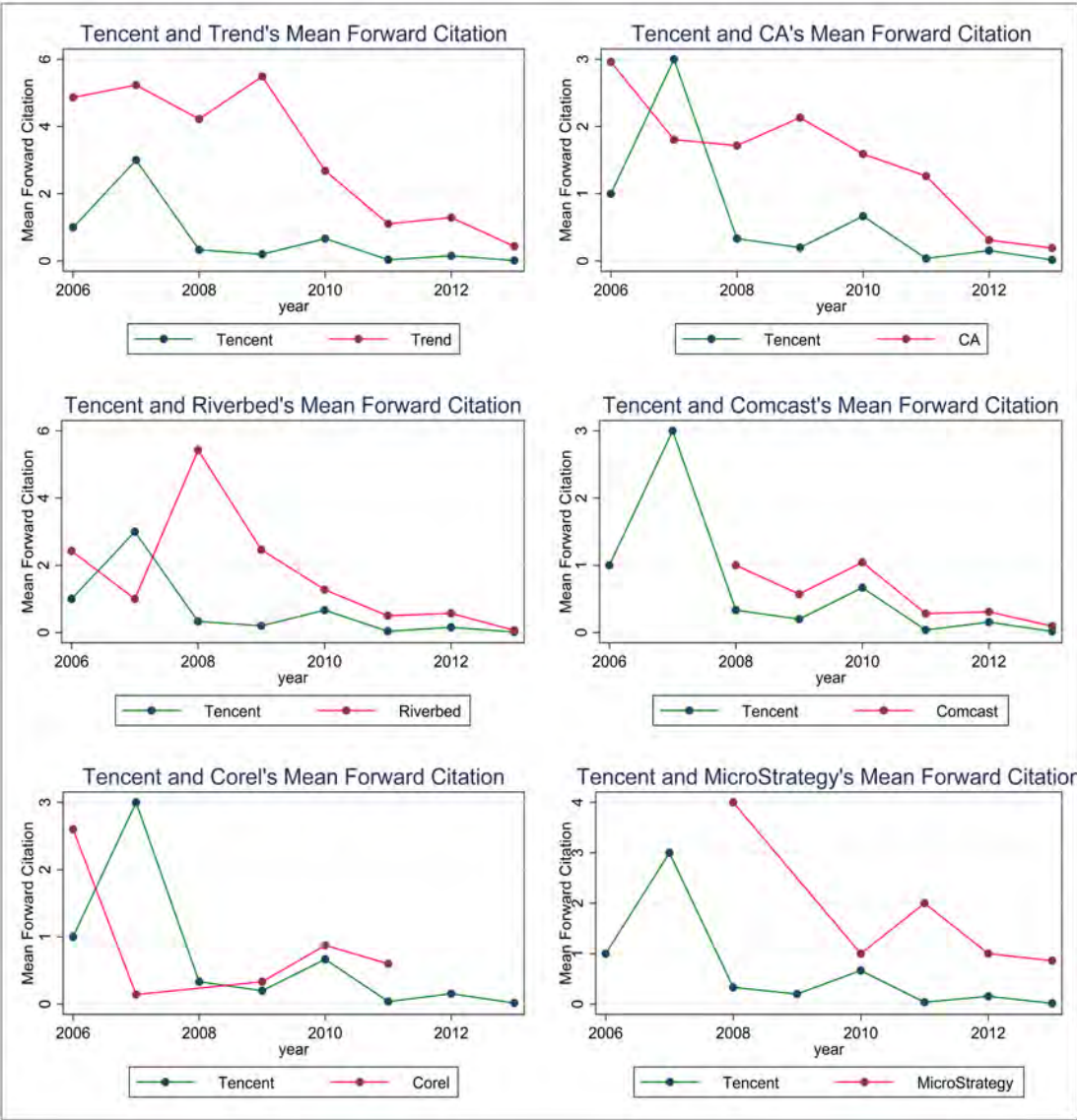


Figure 9.45: Mean Forward Citation–Alibaba and its Competitors (1)

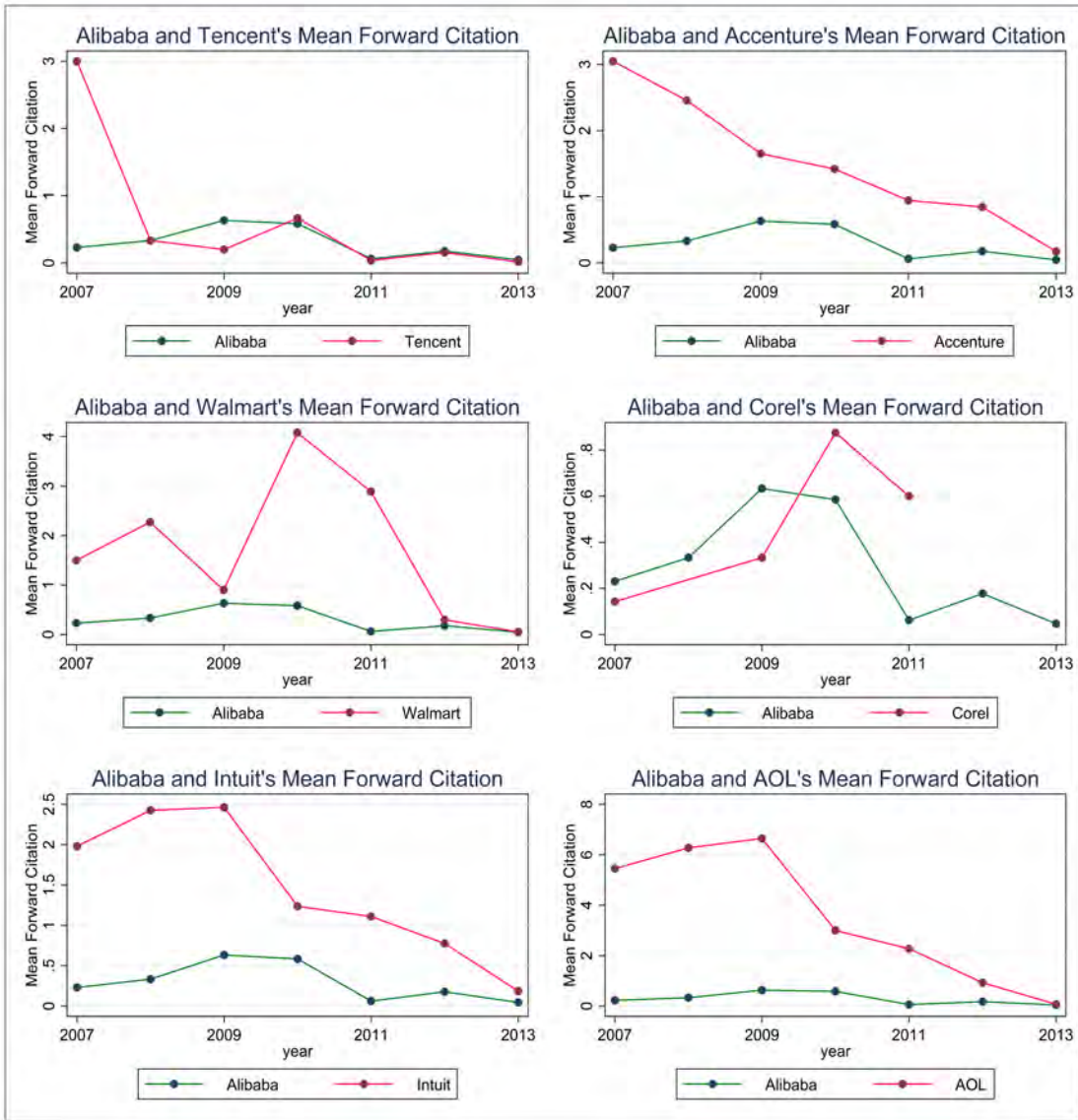


Figure 9.46: Mean Forward Citation–Alibaba and its Competitors (2)

