Building China's High-Tech Telecom Equipment Industry: A Study of Strategies in Technology Acquisition for Competitive Advantage

by

Aleyn Smith-Gillespie

B.A., Natural Sciences
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Submitted to the Department of Urban Studies and Planning and the
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ABSTRACT

Over the past decade, China has witnessed a rapid growth in its information and communications technology (ICT) sector. The subject of this thesis specifically focuses on the telecommunications infrastructure equipment industry in China. This sector is an interesting one to study given that some of the leading domestic companies have mostly emphasized developing their own capabilities in product development, rather than calling upon formal technology transfers through foreign direct investment (FDI) initiatives. A significant challenge faced by local firms, however, is that foreign equipment manufacturers possessing deeper technological resources dominate their domestic market. Nevertheless, Chinese enterprises have recently begun producing high-end equipment such as core/backbone routers and DWDM optical transmission systems. The basic question this thesis seeks to answer, therefore, is how can Chinese companies become technologically competitive within the high-end segments of the telecom equipment market?

A case study methodology was used to address this question, focusing on two leading domestic firms: Huawei Technologies, a privately owned company, and ZTE Corporation (Zhongxing), a state-owned enterprise. The findings show that four factors have contributed to the competitiveness of domestic firms. Firstly, they are able to successfully leverage the configurational nature of communications technology. Secondly, the substantial investment made by the case study firms to develop their own R&D capabilities has enabled them to become 'close followers' of the world technological frontier. Thirdly, the global trend towards a less vertically integrated equipment industry has produced a base of suppliers from which Chinese firms can procure world-class component and subsystem technologies. Lastly, the role of the Chinese government has been instrumental in building technological capabilities at the national level and expanding market demand. Reciprocal arrangements and performance requirements established between government and domestic firms have encouraged the latter to upgrade their technological capabilities.

These combined observations provide a perspective on firm competitiveness in high tech industries that is somewhat different to the models proposed under 'second mover advantage' theory. Furthermore, the analyses made of technology acquisition at the level of the firm highlight the importance of independent development (where possible), compared to FDI, as a vehicle for technological development within late industrializing economies.

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Aleyn Smith-Gillespie earned his B.A. in the Natural Sciences from the University of Cambridge, England, between 1994 and 1997. He subsequently joined ERM, an environmental consulting firm based in London, where he worked on a variety of international policy and management issues for both public and private sector clients. He is currently enrolled at MIT as a dual degree candidate in the International Development and Regional Planning Group of the Department of Urban Studies and Planning (DUSP), and in the Technology and Policy Program (TPP) – an inter-departmental program within MIT's Engineering Systems Division.

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Tables and Figures

List of Abbreviations

Companies and Organizations

BISC	Beijing International Switching System Corporation
GATT	General Agreement on Tariffs and Trade
MEI	Ministry of Electronics Industry
MII	Ministry of Information Industry
MPT	Ministry of Posts & Telecommunications
NPC	National People's Congress
PTA	Provincial Telecom Authority
PTIC	Posts & Telecommunications Industry Corporation
SETC	State Economic and Trade Commission
SDPC	State Development and Planning Commission
WRI	Wuhan Research Institute
WTO	World Trade Organization
ZTE	Zhongxing Telecom Equipment Corp.

Technical Abbreviations

ASIC	Application Specific Integrated Circuit
ATM	Asymmetric Transfer Mode
CDMA	Code Division Multiple Access
DWDM	Dense Wavelength Division Multiplexing
Gbps	Gigabits per second
GPRS	General Packet Radio Service
GSM	Global System for Mobile
IP	Internet Protocol
LAN	Large Area Network
OADM	Optical Add Drop Multiplex
SDH	Synchronous Digital Hierarchy
SONET	Synchronous Optical Network
TDMA	Time Division Multiple Access
WDM	Wavelength Division Multiplexing
3G	Third Generation (mobile communications)

Other Abbreviations

FDI	Foreign Direct Investment
ICT	Information and Communication Technology
IP	Intellectual Property
ISP	Internet Service Provider
IT	Information Technology
JV	Joint Venture
ODM	Original Design Manufacturer
OEM	Original Equipment Manufacturer
SME	Small and Medium Enterprise
WOFE	Wholly Owned Foreign Enterprise

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To all the people interviewed, I would like to thank them for having so enthusiastically and generously given of their time. I thoroughly enjoyed our interview sessions, which brought to life the stories behind the emergence of China's telecom equipment industry. I feel privileged to have been granted access to their knowledge and experience, and for having gotten a first glimpse of what promises to become a vibrant sector in China's economy.

I also wish to recognize Professor Alice Amsden of the MIT Department of Urban Studies and Planning, and Professor Edward Steinfeld of the MIT Sloan School of Management for providing me with valuable comments and advice in their capacity as my thesis advisors. Their expertise and experience were very helpful in identifying the right questions to be asked and in providing the intellectual rigor for this work.

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1 Introduction

My initial interest in the topic of this thesis arose from wanting to understand how a late industrializing country such as China has been able to successfully develop a high technology sector. The Chinese telecom infrastructure equipment industry revealed itself to be a particularly interesting case to investigate because of the considerable challenges faced by domestic firms. These include the task of acquiring technological capabilities in a very technology-intensive industry, and competing against foreign companies with a dominant and entrenched position in the Chinese market.

One of the initial sources of inspiration for this research was a book by Xiaobai Shen – *The Chinese Road to High Technology* (Shen 1999). His work was particularly relevant, as it is the only study that analyzes in depth the acquisition of technological capabilities by Chinese firms for the production of telecommunications equipment. At the time of his initial research (carried out in 1992), digital switching systems were considered to be the height of telecommunications technology in China, and his research focused on the different experiences and strategies of Chinese firms in acquiring this particular technology from abroad. Since then, the field of telecommunications technology has seen an explosion in the types and uses of equipment including mobile, optical and data communications products and systems.

Another dramatic change that has occurred has been the dominance of foreign firms, particularly in the high-end communications technologies. Therefore, I wanted to bring Shen's research up to date by understanding how far Chinese firms have evolved since a decade ago, and what strategies, if any, they have employed to become competitive. In particular, the main question I set out to answer was how can Chinese companies compete against foreign firms in the high-end segments of telecommunications equipment?

Given the time constraints, I decided to tackle the question of competitiveness from a technological standpoint. This is because the possession of relevant technological capabilities is a requirement for entry into the lucrative high-end market for this type of equipment. Preliminary research on the industry revealed that certain Chinese firms had managed to manufacture products of a very advanced standard. Therefore, three hypotheses were proposed to explain how domestic firms have achieved their current level of technological capabilities, and how they might use these strategies to successfully compete against their more advanced foreign counterparts:

H1 Heavy investment in internal R&D capabilities is increasingly becoming an important driving force behind the success of certain Chinese companies.

H2 Chinese firms are leveraging the 'configurational' nature of communications technology to avoid the need for costly investment of resources in building technologies from scratch.

H3 International supplier relationships established by Chinese companies have had an important impact on their technological, and hence commercial, competitiveness. The availability of – and ability to purchase – technologies from international sources has been an enabler for Chinese industry.

Research Methodology

A case study methodology was designed to test these hypotheses. The objective of these case studies was to look at the question from the perspective of the firm. This was seen as the best way to understand the detailed process of technology acquisition. Information for these case studies was collected through performing semi-structured interviews in China throughout the month of January 2001 (see *Appendix 1* for the list of interviewees).

Two domestic companies were used as subjects for the case studies: Huawei Technologies and ZTE Corporation[1]. Interviews were performed with managers and staff from these companies as well as those in other domestic and foreign firms in China. This was done in order to obtain both a firm-specific and a sector-wide perspective on the issues.

Thesis Structure

Chapter 2 begins by introducing some basic concepts and frameworks that are useful in understanding the acquisition of technological capabilities. Because foreign companies – be they suppliers or competitors – have an important impact on the Chinese industry, *Chapter 3* covers the telecom equipment sector from an international perspective. This is also used as a basis from which to draw some key implications for Chinese firms that are referred to in later chapters. *Chapter 4* specifically looks at the telecom equipment industry structure in China, and also provides some background on the origins of the sector and its key players. *Chapter 5* discusses the impact that Chinese government policies have had on the domestic industry, particularly with respect to technological catching up. *Chapter 6* presents the two case studies that are the focal point of this thesis, examining in detail the R&D processes and supplier relationships of Huawei and ZTE. *Chapter 7* synthesizes and analyzes the findings of the previous five chapters in order to answer the above hypotheses and thesis question. *Chapter 8* draws some wider conclusions from this research with respect to theories of development in late industrializing countries.

[1] Also known as Zhongxing.

2 Theoretical Concepts of Technology Development

This chapter discusses some of the basic concepts and definitions relating to technological development at the level of the firm. It specifically looks as the issues of technological capabilities, learning, and innovation as they apply to firms in late-industrializing economies.

2.1 *TECHNOLOGY AND LEARNING*

What is Technology?

In order to understand technological change in the context of a late-industrializing country such as China, it is necessary to gain a basic grasp of what "technology" itself means. The term "technology" refers to both a collection of physical processes that transforms inputs into outputs, and knowledge and skills that structure the activities involved in carrying out these transformations. A good definition of technology is provided by Linsu Kim (Kim 1997), whereby "technology is the practical application of knowledge and skills to the establishment, operation, improvement and expansion of facilities for [the transformation of inputs into outputs] and to the designing and improving of outputs therefrom".

An important part of technology is differentiated, tacit, ever-changing and often firm-specific knowledge, accumulated in the process of design, investment, production and marketing (Shi 1998). However, although technology is often firm-specific, it may also have the quality of public goods in that firms benefit from the general stock of technological knowledge. In modern societies, technological knowledge is well articulated and may be codified in the form of blueprints, prototypes, instructions and designs which can be easily understood by experts. Even when technology is not codified (such as skills and know-how), it can often be learned through personal exchange, learning by doing and watching, and other means. Furthermore, firms can learn from other firms through various channels such as reverse engineering or technology licensing. These issues will be further discussed below.

Technological Capabilities, Absorptive Capacity, and Learning

Kim (1997) provided the following succinct summary of what "technological capabilities" mean:

> The term "technological capability" refers to the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt, and change existing technologies. It also enables one to create new technologies and to develop new products and processes in response to a changing economic environment. It denotes operation command over knowledge. It is manifested not merely by the knowledge possessed, but,

> more importantly, by the uses to which that knowledge can be put and by the proficiency with which it is used in the activities of investment and production, and in the creation of new knowledge. For this reason, the term "technological capability" is used interchangeably with "absorptive capacity": a capacity to absorb existing knowledge and in turn generate new knowledge.

Both Kim and Amsden (2000) define technological capabilities according to three categories: production, investment and innovation capabilities. These are further explained in *Table 2.1*. Although "technological capability" is used to describe a firm at one point in time, the term "technological learning" refers to the dynamic process by which companies acquire technological capabilities.

Yizheng Shi (1998) further elaborates on the issue of technological capabilities by arguing that strategic planning demands a certain level of technological knowledge and understanding of current technological developments. Developing countries therefore need properly qualified manpower to assess competing technologies on their own merits and to select those that are found to be most suitable under the circumstance. Moreover, the recipient's knowledge about the technology concerned will be an important factor influencing its bargaining strength, e.g. the information it has about alternative sources of supply, the resources it prepared to expend on getting such information, and, paradoxically, how much it knows about the knowledge it is buying.

2.2 Defining Research & Development: Imitation or Innovation?

Because of the highly technical nature of telecommunications equipment, one of the major themes that pervades the discussion of technological 'catching up' by Chinese firms is the nature of research and development (R&D) that they perform. Therefore, in order to help the reader navigate through the various references to R&D undertaken by the firms studied, it is necessary to establish what the term really means in different contexts.

Imitation

Invariably, industrializing countries have begun their paths of technological development through imitating foreign technologies. This includes both legal and illegal imitation, and differs according to the amount of effort needed to develop these products (depending upon the maturity of the product and the ease with the technology can be acquired). Schnaars (1994) provides a useful classification with which to analyze the type of imitation undertaken by a firm: counterfeits; knockoffs or clones; design copies; creative adaptations; technological leapfrogging; and adaptation to another industry.

Counterfeits and knockoffs are both examples of *duplicative imitation* (counterfeits being illegal whereas knockoffs are generally legal). Duplicative imitation does not necessarily require specialized investment in R&D and information channels. Nevertheless, because in some cases the product technology cannot be obtained through simply looking at the

Table 2.1 Technological Capabilities

Production Capability

Production Management – to oversee operation of established facilities
Production Engineering – to provide information required to optimize operation of established facilities, including the following:

1. Raw material control: to sort and grade inputs, seek improved inputs
2. Production scheduling: to coordinate production processes across products and facilities
3. Quality control: to monitor conformance with product standards and to upgrade them
4. Trouble-shooting to overcome problems encountered in course of operation
5. Adaptations of processes and products: to respond to changing circumstances and increase productivity
6. Repair and maintenance of physical capital, according to regular schedule and when needed

Investment Capability

Manpower training – to impart skills and abilities of all kinds
Preinvestment feasibility studies – to identify possible projects and ascertain prospects for viability under alternative design concepts
Project execution – to establish or expand facilities, including the following:

1. Project management: to organize and oversee activities involved in project execution
2. Project engineering: to provide information needed to make technology operational in a particular setting, including the following:
   a. Detailed studies (to make tentative choices among design alternatives)
   b. Basic engineering (to supply core technology in terms of process flows, material and energy balances, specifications of principal equipment, plant layout)
   c. Detailed engineering (to supply peripheral technology in terms of complete specifications for all physical capital, architectural and engineering plans, construction and equipment installation specifications)
3. Procurement (to choose, coordinate, and supervise hardware suppliers and construction contractors)
4. Embodiment in physical capital (to accomplish site preparation, construction, plant erection, manufacture of machinery and equipment)
5. Start-up of operations (to attain predetermined norms of innovation capability)

Innovation Capability

The skills necessary to create new products or processes, the type of skills depending on the novelty of the new technology.

1. *Pure science*: the search for intrinsic knowledge
2. *Basic research*: the search for radically new technology
3. *Applied research*: the search for differentiated products
4. *Exploratory research*: the search for refinements of differentiated products
5. *Advanced development*: the search for optimum manufacturability of refined products

Source: Amsden (2000).

production process involved, it must be acquired through other means. At one extreme lies *reverse engineering*, where the production involved may be a novel combination of highly standardized technological elements. In this case, reverse engineering efforts may result in the identification of those elements and the nature of their combination, resulting in an economically successful imitation. At the other extreme, the technology may be so idiosyncratic and firm specific (or the technological capabilities of the imitator so poor), that substantial help is required by means of a *formal technology transfer* from the originator. In both cases, considerable internal capability is needed to identify the nature and source of relevant technology, to negotiate its transfer or reverse-engineer, and to assimilate it[1].

Design copies, creative adaptations, technological leapfrogging and adaptation to another industry are *creative imitations*. Creative imitations aim at generating similar products but with new performance features, and involve activities such as benchmarking and strategic alliances. In addition, these types of imitation involve learning through substantial investment in R&D.

Innovation

Innovation can be defined as a pioneering activity – rooted primarily in a firm's internal competencies – to develop and introduce a new product to the market. As the first firm to establish itself in the market, an innovator benefits from 'first mover advantages' that are unavailable to imitators[2]. However, an important insight that is useful to the context of this thesis is that the distinction between innovation and imitation can be blurred. Many skills and activities required in reverse engineering have easily been transformed into activities called 'R&D' as a firm approaches the world technological frontier. Kim (1997) describes this with respect to the Korean industry:

> Reverse engineering involved activities that sensed the potential needs in a market, activities that located knowledge or products which would meet the market needs, and activities that would infuse these two element into a new project. Reverse engineering also involved purposive search of relevant information, effective interactions among technical members within a project team and with marketing and production departments within the firm, effective interactions with other organizations such as suppliers, customers, local R&D institutes and universities, and trial and error in developing a satisfactory result. *Skills and activities required in these processes are in fact the same in innovation processes in R&D* (emphasis added).

This insight helps us understand the nature and implications of R&D within firms in late-industrializing countries (such as those studied in this thesis). Thus, although R&D may be defined in the majority of these cases as relating to reverse engineering activities, they may substantively approach certain types of innovation efforts undertaken by 'first

[1] Duplicative imitation conveys no sustainable competitive advantage to the imitator technologically, but it supports competitive edge in price if the imitator's wage cost is significantly lower than the imitatee's.
[2] These include image and reputation, brand loyalty, an opportunity to pick the best market, technological leadership, an opportunity to set product standards, access to distribution, experience effects, and an opportunity to establish an entry barrier of patents and switching costs (Kim 1997).

movers'. This view is also echoed by Shi (1998). Shi states that the process of unpacking, mastering and assimilating imported technologies requires firms to solve numerous problems, the answers to which are not always provided by the supplier of the technology. Therefore, he argues, the assimilation and reproduction of technology itself involves a process of technological innovation, to a greater or lesser degree.

Amsden *et al.* (2000) propose a system of classification in order to draw international comparisons of R&D activity. This is summarized in *Table 2.2*. The classification follows the five types of innovation capabilities outlined in *Table 2.1*: pure science; basic research; applied research; exploratory development; and advanced development. This system is designed primarily to compare R&D activities of *first movers* and therefore does not incorporate the features of R&D relating to imitation and reverse engineering discussed above. However, this framework is still a very useful one to use for guidance on assessing the type of R&D undertaken by firms in late industrializing economies (even if it is imitative).

2.3 The Social Shaping of Technology

One of the key ideas used in this thesis relates to the theory on the Social Shaping of Technology (SST), as applied by Xiaobai Shen (1999) to the early telecommunications equipment industry in China. Shen draws upon SST theory to analyze the acquisition by Chinese firms of the capabilities to develop switching systems for telecommunications networks. Because he uses SST theory within the context of telecommunications equipment production, it is useful to review these ideas in order to draw from them later in the analysis.

The theory behind the Social Shaping of Technology was developed as a reaction to the linear models of technological innovation which saw this process as a one-way flow of information, ideas and solutions from basic science, through R&D, to the distribution of finalized products through the market to consumers. In essence, SST stresses the fact that certain technologies can be flexible enough to be 'shaped' by users, and this shaping is influence by social, economic and technological aspects of the host environment.

SST sees complex modern technologies as heterogeneous assemblages that are capable in principle of being reconfigured in their implementation and use. In particular, an important feature of information and communications technologies is their *configurational nature*, whereby the combinations of both standard and customized components are configured to meet specific needs.

All this translates into the fact that, when a firm seeks to develop a product which exhibits the characteristics just mentioned, it is able to make certain choices over what to develop itself (and thus learn how to design), and what to simply purchase (and thus leave as a technological 'black box'). The particularly configurational nature of telecommunications technology suggested by Shen means that a firm can combine components it has learnt to design with those purchased from suppliers (for which

Table 2.2 New Typology of R&D Characteristics

	6.0 Pure Science	6.1 Basic Research	6.2 Applied Research	6.3 Exploratory Development	6.4 Advanced Development
Search for	Intrinsic knowledge	New knowledge for radically new marketable product	Differentiated product "on paper"	Prototype in a system	Prototype for manufacture
Research objectives	Uncover new scientific principle	Same as 6.0 but with (unknown) application to gain monopoly rents	Transform, variate and re-apply known application	Implement concept as engineered system	Reduce costs, uncertainties of manufacturing
Output	Concept-based IP (papers, patents)	Product-based IP for transfer to 6.2, 6.3 (papers?, patents?)	Differentiated product for specific market	Detailed product design or prototype	Manufacturable product
Time horizon	Infinite/long-term	Long-term	Medium/short-term	Short-term	Immediate
Techniques	Scientific, experimental and mathematical techniques	Same as 6.0	Scientific techniques (formulation of equations, algorithms)	(New) engineering design tools, including simulation	Same as 6.3 plus testing, Quality Control
Interaction of technique/problem	Both in unexplored space	Same as 6.0 but limited space under study	Uncertain with respect to extension or application into new system	Application of known tools to known problem	Surprises from manufacturing variabilities
Qualifications and skills	PhD in fundamental science, mathematics or engineering	Same as 6.0 plus management experience and oversight	BS/MS/PhD fresh recruits but with experience, up-to-date training	Same as 6.2 but PhD unnecessary	Same as 6.3 plus people-related management skills, process know-how
Size of effort	Depends on piece of knowledge under study	Scale economies related to whole product; critical skill mass; specialization and integration	Smaller critical mass appropriate for exploiting niche hand-me-down from 6.0	Scales up with size of the system	Related to production
Location of activity:	Near skills (in academic or other liberal research environment)	Near skills	Near market (sufficient skills)	Near production (or market?)	Near production

Source: Adapted from Amsden, Goto and Tschang (2000) domestic firms may not have the technological capabilities to produce themselves). Thus, not only can a producer of telecommunications equipment potentially 'punch above its weight' in terms of technological capabilities, but it can also choose which of these capabilities to master (as well as *when* to do so). This insight has implications for late-industrializing countries such as China both in terms of technology strategies at the level of the firm, as well as government policies seeking to develop national industries.

Shen classifies the potential for local shaping of foreign technology by latecomer firms according to their form, scale and complexity. He therefore distinguishes between three types of technologies: discrete technologies; systems technologies; and configurational technologies.

- *Discrete technologies.* Are stand-alone technologies designed to carry out specific and common functions independent of context. An example is a word processor or computer-controlled machine tool.
- *Systems technologies.* These typically relate to a wider range of activities than discrete technologies, and are thus more tightly linked to particular application settings. Typically, system technologies need to be adapted for use in developing countries in order to fit them to the their different requirements and circumstances. System technologies tend to be rather rigid in their construction and may be difficult or costly to adapt, an example being certain telecom switching systems[3].
- *Configurational technologies.* These technologies match the complexity of systems technologies (in the range of applications they can be used for), but are designed to allow great flexibility in development and application. Development costs are reduced by drawing upon existing components technologies which can be selected according to the particular uses of the final product. This makes it more flexible for developing countries to reconfigure such solutions to their local needs and exigencies.

According to Williams (1997), information and communications technologies (ICT) in particular are increasingly taking the form of configurational technologies since both modular design and the use of open standards can facilitate the substitution of internal components. The selection of components and design for flexibility in application can make it easier to adapt them to meet the specific needs of a wide range of users. SST theory suggest that, because foreign technologies can be locally configured (in the developing country) to meet local criteria – such as being suitable for local production and local markets, using local resources, etc. – configurational technologies extend the scope for *recipient-side innovation*.

[3] Such as the System-12 public digital switching system described by Shen (1999).

3 An International Perspective on the Telecom Equipment Manufacturing Sector

3.1 *Introduction*

In order to place the strategies employed by Chinese telecom equipment companies – and the government policies designed to foster their growth – in their proper context, it is necessary to first consider the dynamics of this industry in the West where it is more established. This chapter therefore deals with the international models of industrial structure within the telecom infrastructure equipment industry. The relevance of looking at these models also comes from the fact that most, if not all, of the large OEMs in these industries are direct competitors of domestic firms in the Chinese market. Furthermore, some of the major component suppliers in the industry are either beginning to establish supplier relationships with Chinese firms, or starting up operations within China.

The material discussed here will focus on the optical equipment industry and the router/data networking industry, which are the main focus of the two case studies examined in *Chapter 6*. This chapter also looks at the wireless equipment industry since this is a major area of growth for Chinese companies and is useful in later drawing conclusions from a sector-wide perspective.

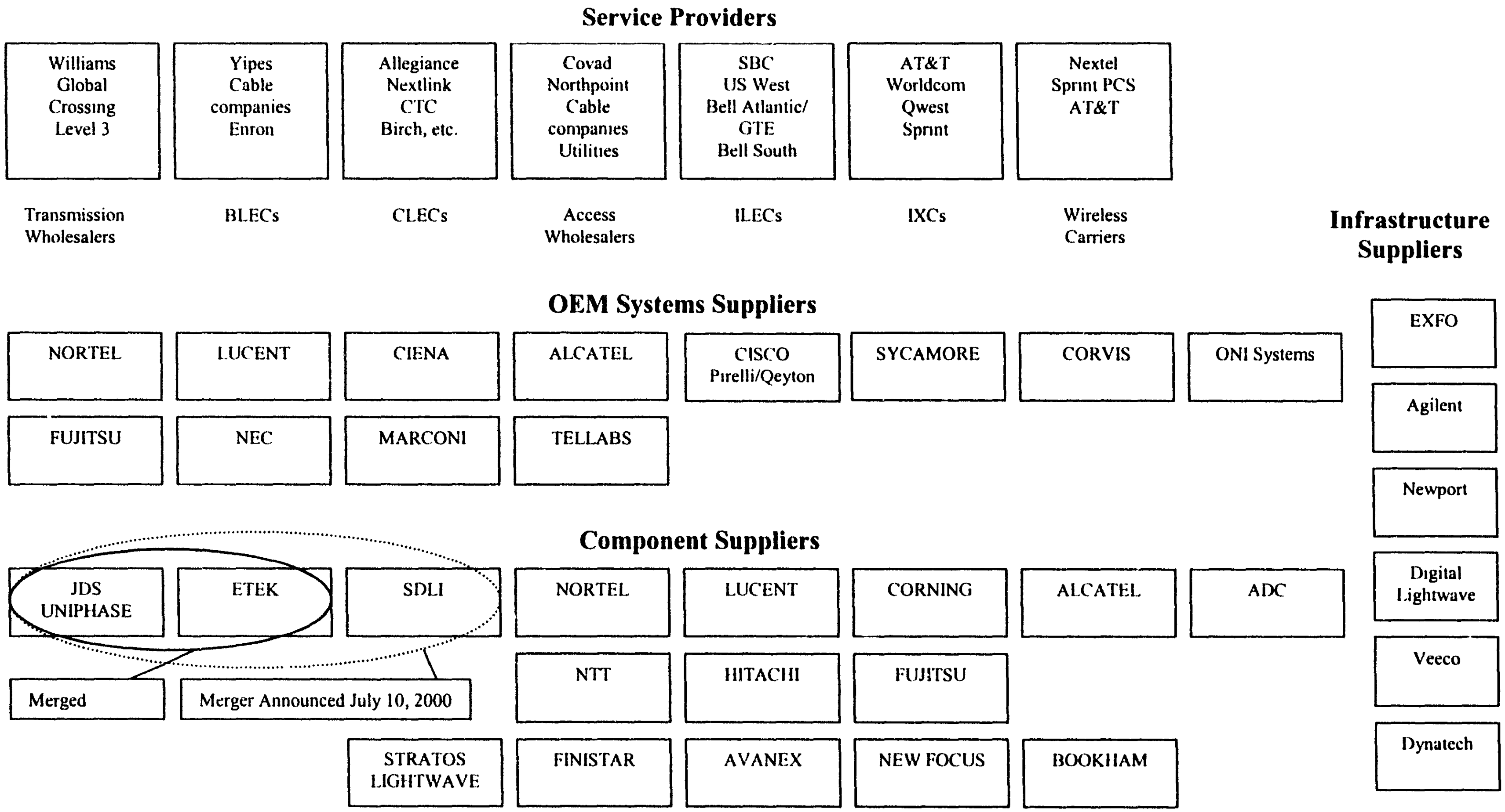
3.2 *Optical Communication Equipment*

Figure 3.1 shows a simplified version of the supply chain structure within the optical communications equipment industry. The optical equipment industry is broadly divided into two segments: the OEM *systems providers*, who manufacture entire pieces of optical systems and equipment, and the *component suppliers*, who design and manufacture the specialized components needed by the former. As can be seen from the diagram, certain companies are both systems providers and component manufacturers. *Appendix 2a* presents a diagram illustrating the network of relationships between component suppliers and systems providers.

As will be explained below, there are five major trends currently occurring within the optical equipment industry:

- Industry consolidation;
- an active components sector rapidly sprouting new entrants and new products;
- an emphasis on manufacturing skills and expertise as a key to success;
- better component integration being offered by suppliers to the systems providers; and
- less vertical integration, with a cleaner separation between optical components suppliers and systems providers.

Figure 3.1 Photonic Supply Chain (Public Companies)



Source: Merrill Lynch (2000a)

Optical Systems Providers

The 'Big Three' optical systems providers are Nortel, Lucent and Alcatel which occupy 33%, 13% and 11% of the global market, respectively[1] (Merrill Lynch 2001). *Table 3.1* lists the major systems providers and their market shares, for all optical systems categories combined.

Table 3.1 Global Market Shares of Publicly Traded Optical Systems Providers

Company*	Ticker	Market Share
Nortel Networks	NT	33%
Lucent Technologies	LU	13%
Alcatel	ALA	11%
Fujitsu		9%
Tellabs	TLAB	6%
Marconi	MONI	5%
NEC		5%
Cisco	CSCO	4%
Ciena	CIEN	3%
Siemens		3%
Other*		8%
- Adva		
- Corvis	CORV	
- Ericsson	ERICY	
- Hitachi		
- Osicom		
- Redback	RBAK	
- Sycamore Networks	SCMR	

* Companies under 'other' are ordered alphabetically.

Source: Morgan Stanley Dean Witter (2000)

Nortel has made a series of acquisitions over the past years which include both smaller competitors with desirable technologies (Cambrian, Xros and Qtera) and components manufacturers (Core Tek) (Merrill Lynch 2001). Alcatel is another among the three whose operations also include component manufacturing, although this is in the form of a subsidiary – Alcatel Optronics – which also supplies other systems providers with components. Of the smaller systems vendors, Hitachi also includes a component manufacturing division which is well regarded despite the fact that the company has a small share in the systems market (Merrill Lynch 2001).

Given that key breakthroughs in optical technology occur at the component level (see below), systems providers seem to have adopted either of two strategies in order to compete. The first is typified by Sycamore Networks, which is to leverage the work of

[1] Nortel has a 51% share for terrestrial DWDM and 30% for SONET/SDH systems. Lucent leads the market in Asia-Pacific with a 25% market share of the WDM market and 15% of the SONET/SDH market. These figures do not include submarine optical systems. When included, Alcatel takes second place overall with a 20% market share (as it leads the submarine market with a 41% market share). Merrill Lynch (2001).

several component suppliers and then to add value – and product differentiation – mostly through system level architecture and software. The second strategy, followed by Nortel and Ciena, is to use some in-house components to provide advanced level functions while outsourcing to others for the non-differentiating features. The most proven method to date is that of Nortel (given its success). However, industry analysts believe that, as the industry matures, component suppliers become stronger (in technology and manufacturing), and the need for intensive R&D increases, it will be harder for strictly in-house component shops to compete (Merrill Lynch 2000a).

Sycamore Networks: Example of an Outsourcing Strategy

A key strategy of Sycamore is to outsource component development and manufacturing, while directing its energy on software, intellectual property and marketing. Sycamore purchases components from suppliers such as Corning and AMCC, and purports to work closely with its suppliers to develop the needed components. They do not place restrictions on their suppliers to limit sales of co-developed components to other companies. Although Sycamore may lose some competitive advantage because of this strategy[2], it is believed that they are able to win with time to market and by being able to purchase many piece-parts at commodity prices (Merrill Lynch 2001).

Sycamore also outsources the manufacturing of its systems, which has helped them scale up without enormous capital investments. In order to do this, Sycamore has enlisted contract manufacturers such as Jabil Circuit and Celestica to assemble, test and ship its systems. Although some early hiccups were reported as the manufacturers ramped up the assembly of their products, it is believed that the processes are improving (Merrill Lynch 2001).

Core Competencies: Software and Systems Engineering

The core competencies of optical systems providers are in systems engineering and software engineering – not component or even module manufacturing. Software, or 'soft optics', that is integrated around the optical systems is what differentiates competitors' products. A portion of the software acts as the 'brains' of the network element, while other functions include databases for storing user information, communication protocols, and network management systems. Arguably the most intensive engineering activities relate to software development (Merrill Lynch 2001).

Optical Components/Modules Suppliers

Component companies play a critical role in supporting the optical equipment supply chain. It is at the component level that many technological breakthroughs have been achieved, such as EDFAs, tunable lasers, AWGs and RAMAN amplifiers, which are the crucial building blocks for the systems providers. By incorporating these key 'enabling'

[2] Although this may have helped the company's rapid growth, a possible draw-back of this is a lowered ability to differentiate its products from the competition.

technologies into their product portfolios, systems providers can offer the technical capabilities within their equipment which is demanded by their service provider customers (Merrill Lynch 2000a).

The leading component suppliers, and their respective market shares, are JDS Uniphase (28%); Nortel Optoelectronics (27%); Lucent Microelectronics[3] (13%). *Table 3.2* provides a summary of the publicly-traded component manufacturers and their market shares. The leading companies support strong product portfolios and it is believed that, as the component arms of the systems providers become more independent, they will introduce more competition into the merchant market for components (Merrill Lynch 2000a).

Table 3.2 Publicly Traded Optical Components Suppliers

Company*	Ticker	Market Share**
JDS Uniphase	JDSU	28%
Nortel Networks (Optoelectronics)	NT	27%
Lucent Technologies (Microelectronics)***	LU	13%
Corning	GLW	10%
ADC Telecom	ADCT	9%
SDL Inc****	SDLI	5%
Alcatel (Optoelectronics)	ALAO	5%
Hitachi	HIT	2%
Stratos Lightwave	STLW	1%
Alliance Fiber Optic Products	AFOP	-
Avanex	AVNX	-
Bookham	BKHM	-
Finisar	FNSR	-
Luminent	LMNE	-
New Focus	NUFO	-
OCPI	OCPI	-
Oplink	OPLK	-

* Companies are ordered by market share, when this information is available (from Merrill Lynch 2000a).
** A dash ('-') indicates companies whose market share is not known but which are smaller publicly traded players, in which case they are listed alphabetically (from MSDW 2000b).
*** Recently floated as Agere, its new name.
**** Acquired by JDS Uniphase.

Source: Merrill Lynch (2000a) and Morgan Stanley Dean Witter (2000b)

JDS Uniphase is viewed as the most competitive in the component space as it supports the broadest product portfolio in the business, including both 'passive' and 'active' components. The 'spinouts' of the systems providers are still primarily focused on 'active' components and have a concentrated customer base with the respective parents

[3] Now known as Agere, it has been recently floated as a separate company.

representing a substantial portion of sales[4]. Corning's Photonics business has significantly broadened its portfolio of active and passive components like EDFAs. It has also benefited from the need of the systems providers to have an alternate component supplier (Merrill Lynch 2000a).

The future holds a growing number of new entrants in the components business, many of which are on the IPO track (see *Appendix 2b*).

The Strategic Role of Components

It is believed that innovation in optical networking will be driven by components and it is these suppliers who will enable the technologies for the systems providers. Merrill Lynch (2000a) claims that the optical component suppliers are "closer to science" than any other communications equipment sector, and possibly more than any other IT sector. Components are thus the key enablers of more wavelengths, faster data rates, longer optical reach, and more flexibility at the wavelength layer[5].

Industry Trends

One of the significant trends in this sector is the separation of component manufacturing from systems provision. There are numerous players within the optical components industry. Several of the large systems providers are now spinning off their internal component arms as separate business entities who will join the ranks of pure-components companies. Examples of this are the spinning off of Lucent Microelectronics, and the establishment of a tracking stock for Alcatel Optronics[6] (Merrill Lynch 2000a).

Although a division of labor between systems and components manufacturing is becoming evident, component manufacturers are providing more integrated modules to their systems customers (rather than just raw components). Driving this trend is the fact that newer systems companies such as Sycamore, ONI Systems and other start-ups are relying on component suppliers to provide greater integration, further up the value chain. Currently, a greater degree of outsourcing of component manufacturing by systems companies is occurring, and it is predicted that component companies will also become more module-level suppliers (MSDW 2000a). A further stage in the division of labor is expected to produce three types of companies in the optical industry (Merrill Lynch 2000a):

[4] JDS Uniphase, however, supports Lucent and Nortel as the largest customers, representing less than 40% of sales combined, with the balance from a number of systems houses as well as other component manufacturers.

[5] It was Southampton University's EDFA that enabled the beginning of the optical revolution. It was also Nortel's ability to make 10G componentry that has given it substantial leadership in core optical networks. The ability to amplify, combine, separate, control, switch and measure wavelengths are what will fulfill the future technological leaps in optical networking (Merrill Lynch 2000).

[6] Industry analysts propose three reasons for this trend. The first is that component companies need their own equity in order to take part in mergers and acquisitions, which is of strategic importance within this industry. Secondly, becoming an independent public entity provides companies with stock options which are essential for retaining talent. Thirdly, market valuations for independent component companies are much higher than those which are attached to parent companies.

- Hardware development by component/module suppliers
- Manufacturing assembly by outsourcing companies[7]
- Software and systems development by optical systems companies

The impact of greater reliance by systems providers on their suppliers is that the latter will have to provide broader product lines (in order to offer a greater integration role), or provide *platform technologies* that can be used to integrate discrete devices. In order to boost product lines, a wave of consolidation has been occurring in the components sector led by JDS Uniphase and Corning. JDS Uniphase has acquired 11 companies at a cost of US$ 60.6 billion between June 1999 and July 2000, including SDL Inc (Merrill Lynch 2000a).

R&D will be key to component suppliers as these companies are expected to become the originators of breakthrough technologies which ultimately impact the performance of optical systems. Merrill Lynch (2000a) believes that the importance of R&D is increasing as the industry matures and that this will ultimately lead to two types of innovators, *very large innovators* and *upstart innovators*. Very large innovators are the likes of JDS Uniphase and Corning as well as the in-house divisions of Lucent and Nortel. Upstart innovators are the newer companies with a limited set of new products, which could ultimately be the mergers & acquisitions targets of larger companies.

In the optical systems sector, systems providers are continuing to diversify their product lines in order to tap into new high-growth markets and to leverage their existing technology and customer bases (MSDW 2000a). For example, Sycamore announced the integration of Sirocco's edge and access switches into its own management system, and ONI Systems unveiled a new regional transport product.

Technology Trends

Although demand for SONET/SDH systems will continue, their use is moving to the edge of the network. Taking their place are DWDM systems which are considered more efficient for optical communications[8]. The market for DWDM systems is expected to increase dramatically over the coming years as demand and product features increase (Merrill Lynch 2001). The major DWDM systems providers and their respective global market shares are Nortel (51%); Lucent (9%); CIENA (9%); NEC (8%); Alcatel (6%); Sycamore (4%); Cisco (3%); Fujitsu (3%); and the remaining 7% is distributed among smaller players (Merrill Lynch 2001).

[7] Already, JDS Uniphase has been outsourcing some of its manufacturing to Celestica, a contract manufacturer.

[8] SONET/SDH is an older technology, whereas DWDM is a newer method of optical transmission which has not yet reached maturity (especially in terms of the software used to ensure system stability and maintenance).

Other cutting edge products being developed and marketed include optical cross-connects and optical switches. The North American market shares for optical cross-connects are CIENA (50%); Tellium (19%); Sycamore (19%); Cisco (6%); and Lucent (6%). Optical cross-connects are a more mature product, whereas all-optical switches are still under development.

Other Issues

Talent Scarcity

Scientific, engineering and manufacturing talent is the most scare resource in the optical industry as it has not been able to keep up with the enormous growth witnessed in the past years (Merrill Lynch 2000a). The industry requires people with relevant Masters or Doctorate level degrees and few schools are able to produce them. According to Merrill Lynch, the battle for talent will necessitate companies to provide equity incentives (stock options), offer the prospect of working on cutting-edge technology, and provide attractive working conditions.

The importance of Manufacturing

In spite of leading science and products, it is the ability to efficiently and effectively manufacture optical components which sets companies apart. In particular, given the large demand, it is crucial for companies to have scalable manufacturing capabilities. The following issues need to be addressed in order to achieve this (Merrill Lynch 2000):

- Design for manufacturability in R&D
- Physical manufacturing space
- Sourcing and training manufacturing personnel at reasonable cost
- Sourcing, installing and maintaining manufacturing equipment
- Sourcing materials and other basic components
- Use of mechanization and automation
- Process engineering
- Use of outsourcing at appropriate times

The labor-intensive nature of manufacturing optical equipment (due to the current inability to automate) is encouraging companies to open facilities in low-cost countries such as in the Far East and Mexico. One example is JDS Uniphase, which is establishing a manufacturing base in China[9]. Due to the technical difficulties of achieving efficient manufacturing, many companies view their processes as trade secrets and are unlikely to share them with third party manufacturers (Merrill Lynch 2000).

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[9] See *Chapter 4*.

3.3 *INTERNET ROUTER EQUIPMENT*

The manufacturers of Internet routing equipment fall within a broad range of companies classified under networking equipment providers (sometimes referred to as 'data-communications' equipment). This type of equipment includes routers, LAN/WAN switches, media hubs, etc. – all of which are integral parts of the Internet infrastructure.

Over the past two years, the Internet router category has changed considerably, with the emergence of three separate sub-segments of the market (MSDW 2000b):

- *Core Routers.* These are used in the backbone of the networks. They are developed for maximum throughput and capacity.
- *Edge Routers.* These are used for line aggregation such as broadband (DSL and Cable) and corporate access (T1, T3, OC-3). These routers have smaller footprints and highter interface densities and flexibility.
- *Service Routers.* These are used by telecom carriers to deliver services to customers. They are generally smaller boxes with a greater amount of application software.

The technology employed for core routers is the most advanced due to the capabilities needed to handle vast amount of data at high speeds.

Internet Router Vendors

By far the market leader in all router categories is Cisco Systems. *Table 3.3* shows the other market contenders in two broad categories: the general edge/service routers and 'next generation' core routers. In the first category, Nortel is the main second contender (through its acquisition of Bay Networks). In the second category, Juniper Networks is the only other company with serious market share[10].

Table 3.3 U.S. Market Shares for High-End 'Next Generation' Internet Routers

Company	**Ticker**	**Market Share** **General Edge Routers**	 **Next Generation (Core) Routers**
Cisco	CSCO	89%	69%
Nortel/Bay Networks	NT	4%	-
3Com		1%	-
Juniper Networks		-	30%
Avici		-	1%
Other		6%	-

Source: Merrill Lynch (2000b) and Morgan Stanley Dean Witter (2000b)

[10] The reason that market share in next-generation core routers is less tilted towards Cisco is that customers for these types of routers – namely telecom carriers – customarily employ 'second sourcing' as a policy. That is, ensuring another source of supply for router equipment in order to decrease price and ensure adequate supply. This therefore provides an opportunity for other entrants to build market share.

Cisco Systems

Cisco is the dominant supplier of the routers and switches that run the Internet. One of the most remarkable attributes of Cisco is its unparalleled record of acquisitions – a total of 71 acquisitions between 1993 and 2000 (MSDW 2000b). Each of these acquisitions have been strategic in that they have generally brought three types of benefits to Cisco: (1) entry into new, lucrative and fast-growing markets by instantly acquiring a range of marketable new products; (2) technological expertise through the assimilation of the target companies' engineers and in-house R&D; (3) more management talent by integrating target companies' managers into the company structure.

Cisco is not known within the industry for producing breakthrough technologies on the strength of its in-house capabilities. It is, however, expert at acquiring them by buying companies[11]. A look through the list of assimilated companies reveals that eight of these acquisitions were in the area of router technology, some of which specifically related to either software or ASIC development – the two key technologies for router systems producers.

Within the broad definition of networking equipment, Cisco has a relatively diversified product range (see *Table 3.4*). Recently, it has also entered the optical equipment market through several acquisitions (see *Section 3.2* above).

Table 3.4 Cisco's Market Share for Selected Products (N. America)

Product Category	C3Q00 Share
Ethernet switches	59%
Low-end routers	88%
Mid-range voice routers	93%
High-end routers	95%
Gigabit routers	70%
Cable – CMTS	64%
Remote access	27%
SONET/SDH muxes	5%
Core ATM switches	19%

Source: MSDW (2000b)

The Importance of Software and ASICs

Two key elements of intellectual property involved in router production are the *software* and *ASICs* (Application-Specific Integrated Circuits). Advances in ASIC technology undertaken by router manufacturers have been responsible for important improvements in router performance. These ASICs are highly proprietary and a substantial proportion of a

[11] Judicious company acquisitions have become one of Cisco's core competencies, along with the ability to rapidly integrate the newly-acquired products into its sales channel. Traditionally, the most important currency in making these acquisitions has been the offering of its highly-valued stock (stock options are also an integral part of employee incentive schemes along with clear lines of accountability).

vendor's intellectual property is contained within them (BT Alex.Brown 1999a). Both Cisco and Juniper have in the past acquired ASIC development teams (MSDW 2000b).

Similarly, creating the operating system software[12] for the router has been a key differentiator in the market and has contributed much to Cisco's success. It is believed that, despite the important role of advanced ASICs in the router's functioning, the success or failure of individual products is largely determined by the robustness, feature richness and cleanliness of the vendors' routing software (BT Alex.Brown 1999a). Furthermore, certain companies such as Avici are making their software interoperable with that of Cisco and Juniper in order to sell to customers who already have an installed base of equipment from these companies (MSDW 2000b).

Technology Trends: Today's Core is Tomorrow's Edge

The requirements of Internet infrastructure are drastically increasing. This poses a threat to equipment vendors whose products could face obsolescence in a matter of months as bigger and faster products are introduced. In the router market, products that are originally introduced as core routers are inevitably moved to the edge as technological advances in core networking are implemented.

Router Components Suppliers

Many component suppliers for router equipment are similar to those generally used within the IT and electronics industry. The extent to which router vendors rely on them depends upon their internal capabilities. For example, Avici outsources several components, including its proprietary ASICs, from single or a limited number of sources. Examples of components purchased include optical components, field programmable gate arrays, and a variety of ASICs (MSDW 2000b). With respect to ASICs, larger companies such as Cisco may purchase entire ASICs design houses, as described above, thus obviating the need to source them from suppliers.

Because of the recent boom in Internet infrastructure construction, supply of certain components has been constrained. In such conditions, some of these components are at times subject to allocation (MSDW 2000b).

3.4 Mobile Infrastructure Equipment

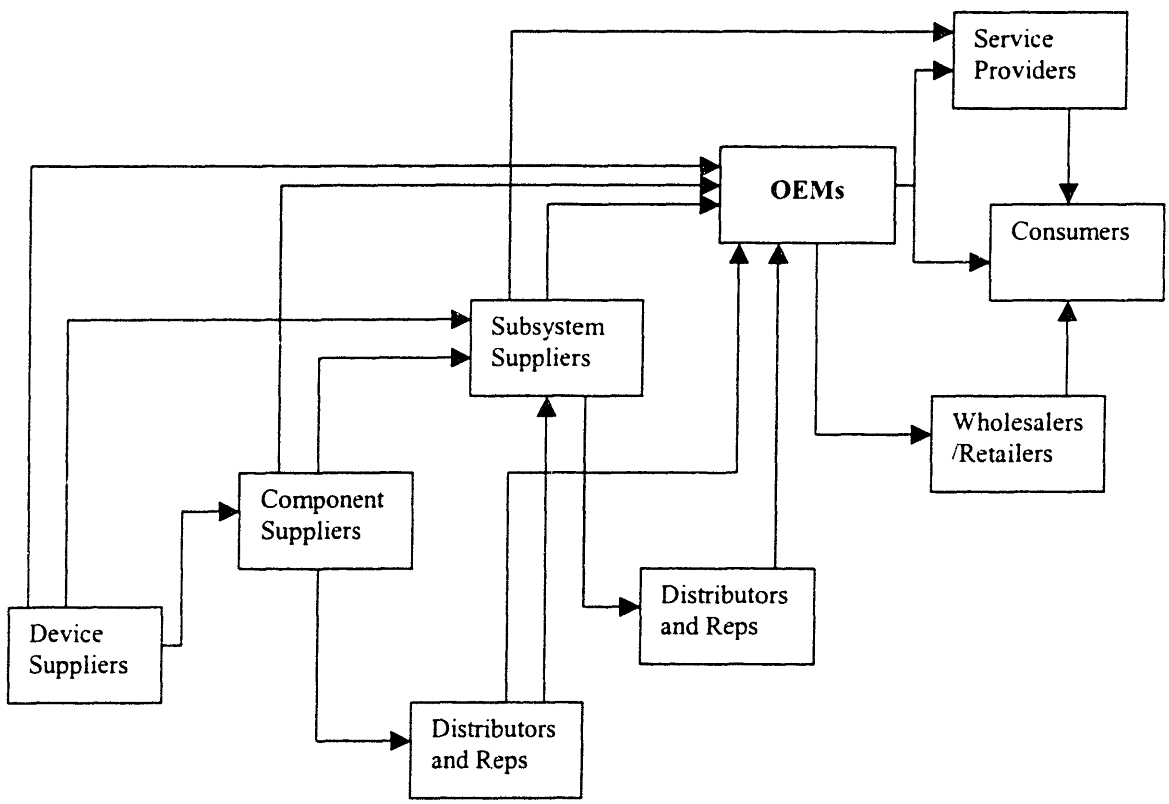
Mobile telecommunications[13] is an R&D-intensive, rapidly evolving sector with numerous companies, large and small, involved in the development, manufacture, and marketing of equipment and services. The mobile infrastructure equipment markets are dominated by a relatively small number of large OEMs who have the size, financial

[12] Operating Systems run the router hardware and allow it to effectively operate within its network environment.
[13] Also referred to as wireless, cellular, or PCS.

strength, global reach and technology leadership to maintain a strong presence in regions throughout the world. Mobile service providers contract with OEMs to plan, manufacture, integrate, install, and in many cases to manage their mobile networks.

Although the OEMs manufacture a number of subsystem products for use in their networks, an array of independent subsystems suppliers provide the OEMs with hardware that is complementary and/or competitive to their internal capabilities. It is believed that many large systems providers will turn to outside vendors for more of their subsystem products[14] (BT Alex.Brown 1999b). However, the dominance of the OEM in the mobile infrastructure market remains paramount (BT Alex.Brown 1999b). *Figure 3.2* shows a schematic of the mobile infrastructure supply chain.

Figure 3.2 The Mobile Communications Industry Structure



Source: BT Alex.Brown (1999b)

[14] Less frequently, the network operator will also purchase individual components directly from a subsystem provider.

Mobile Infrastructure Systems Providers

There are five leading OEMs in the mobile infrastructure market: Ericsson, Lucent, Motorola, Nokia and Nortel. In addition, there are several regional and second-tier OEMs such as Siemens, Alcatel, Hughes Network Systems, NEC, Hitachi, Fujitsu, Samsung, Hyundai, and LGIC.

Ericsson is the market share leader globally based on its leadership in two important segments, GSM and TDMA (where it holds the top position in both)[15]. Nokia has also gained market share in the GSM market (it is number two), based in part on its dominance of the GSM 1800 segment[16] (BT Alex.Brown 1999b).

Lucent is strong in CDMA (number one position) and TDMA (number two position), which are the largest digital standards in the U.S., but has been less active in international markets. In the case of Motorola, it has been a pathfinder in the mobile industry and has won significant GSM and CDMA contracts. Although Motorola has had problems due to its lack of an internally manufactured switch, it is addressing these issues through closer partnerships with Alcatel and Cisco, who supply them. Nortel has also been a significant player in all digital standards, and recent reports are that the company's mobile infrastructure business is gaining momentum (BT Alex.Brown 1999b). *Table 3.5* summarizes the major OEMs and their respective market shares.

Table 3.5 Mobile Infrastructure Market Shares (all standards combined)

Company	Ticker	Market Share*
Ericsson	ERICY	32%
Motorola	MOT	17%
Nokia	NOK	12%
Lucent	LU	11%
Nortel	NT	8%
Other	-	20%

* Based on percentage of global installed base.

Source: BT Alex.Brown (1999b)

Technology Trends: Third Generation Networks

The major OEMs (and their suppliers) are developing new mobile network equipment for the advent of third generation (or '3G') wireless communications. 3G is based on a new communications standard (of which there are several competing versions) which allows the transmission of greater amounts of data. Although many networks will upgrade to 3G via an intermediate '2.5G' standard, technologically speaking it is a large step-change in

[15] GSM is the largest digital standard accounting for over 50% of all global cellular/PCS subscribers. GSM is deployed exclusive of any other digital standard in Western Europe and is the most widely deployed standard in China. TDMA is a smaller, but rapidly growing standard in North and South America.
[16] GSM systems deployed at 1800 MHz, the European equivalent of PCS frequencies in the U.S.

the industry and has necessitated much R&D effort and cooperation among OEMs, suppliers and telecom carriers.

Mobile Infrastructure Component and Subsystems Suppliers

Component and subsystems suppliers exist as either independent companies or business units within the large OEMs. Furthermore, there are several privately-owned companies appearing on the market with new component and subsystem technologies which will be particularly useful as networks evolve to 3G. *Table 3.6* shows a selection of the leading suppliers and their principal products.

Table 3.6 Mobile Infrastructure Components and Subsystem Suppliers

Company	Ticker	Main Products
Digital Microwave Corporation	DMIC	Leading independent manufacturer of point-to-point wireless microwave communications systems. Products include microwave radios for low, medium, and high capacity applications, available for a wide range of frequencies and transmission capacities.
Powerwave Technologies	PWAV	Designs, manufactures and markets ultra-linear radio frequency power amplifiers, which are integral components of wireless communications base stations in cellular and PCS networks.
Qualcomm Inc.	QCOM	Developer and manufacturer of digital wireless communications products and services based on CDMA digital technology. Major business areas include CDMA phones, ASICs, technology licensing, and satellite-based systems. Recently sold its infrastructure segment to Ericsson. Is a leading provider of CDMA chipsets for phones and base stations.
Tekelec	TKLC	A leading supplier of innovative network switching solutions and advanced diagnostic systems. Tekelec's Eagle platform is designed to meet the complex requirements of the converged IP/SS7 network and traditional SS7 networks, enabling wireline, wirless and IP network operators to deliver intelligent network services.
Conductus	-	Develops, manufactures and markets electronic products based on High Temperature Superconducting (HTS) Technology. It has developed HTS filters for wireless base stations. The company also undertakes contract research programs, mainly for government.
Illinois Superconductor Corporation	-	Develops, manufactures and markets high performance front end equipment products for the wireless market based on its proprietary high temperature superconductor materials. It is focussing on tower-mounted HTS filter systems capable of operating under harsh conditions. In May 2000 it acquired Spectral Solutions Inc. (SSI).
Metawave Communication Corp.	-	Provides capacity enhancement solutions to the wireless industry. It designs, develops and manufactures smart antennas for CDMA 800 MHz and GSM 1800 MHz networks. The company is viewed as a leader in the smart antenna technology. In September 2000, acquired Adaptive Telecom Inc which develops embedded array technology for use in 3G networks.
Superconductor Technologies	-	Develops, manufactures and markets electronic products based on HTS technology, focussing on HTS filters for wireless base stations.

Source: BT Alex.Brown (1999b), and Hoefer & Arnett (2001).

3.5 *Trends in Communications Technology Towards Greater Configurability of the Network*

Chapter 2 described a framework presented by Shen (1999) that communications technology is 'configurational' by nature. Shen used this framework to describe the SPC switching technology being developed by Chinese firms in the early 1990s. It is therefore necessary to bring this concept up to date.

Two papers describe the general trend towards greater 'configurability' (alternatively referred to as modularity, compatibility, or inter-operability within various contexts). It is relevant to discuss the issue in this chapter as these technological trends are affecting firms globally as well as having an impact on the industry structure.

The first paper, by Bjorkman *et al.* (2001), describes the movement that is occurring from 'monoliths' to 'component-based network elements'. It states that, historically, equipment vendors have provided telecom operators with monolithic equipment built to provide one or several related functions. This was a reasonable approach from the vendor's perspective, since many of them were only in a single business area (i.e., router companies or telephone switch companies). In general, this was also fine with the service providers as well, since they were often themselves in a single industry (i.e., Internet service providers, ISPs, or telephone companies). With the advent of convergence between communications services involving voice and data, it is no longer true that service providers provide a single kind of service. Similarly, equipment vendors are beginning to provide equipment for a diverse range of services. It is difficult, however, for vendors to provide all the services a customer might desire as the permutations of possibilities becomes too large and is very dynamic over time. Instead, the vendor will have to choose one or two services that fit nicely together and bundle them into its new units. However, from the service operator's perspective, this means that it will need to deal with a variety of vendors offering equipment that do not necessarily combine seamlessly to provide the required range of services it wishes to implement. Because of these changes, the traditional monolithic approach in which the success of the operator is tightly coupled to the decisions and capabilities of a single equipment vendor is starting to break down.

Replacing the monolithic model is the component-based system architecture. Although different versions of this architecture are being proposed, one common feature is that 'critical interface points' are open and defined in detail. These open definitions allow for diverse equipment vendors to build function-specific equipment able to be matched with equipment from other vendors. This leads to flexibility for operators who no longer have to make all-or-nothing decisions when building networks. At the same time, the potential for market growth for equipment vendors is tremendous as operators previously tied to specific suppliers become potential customers.

Bjorkman *et al.* State that both large and small service providers and equipment vendors are aligning behind this new network model. *Table 3.7* describes various forums that have been set up to foster different aspects of the component-based network architecture:

Table 3.7 Forums to Promote Component-Based Architectures

Forum	Purpose	Members
Multiservice Switching Forum (MSF)	The MSF's mission is to accelerate the deployment of open communication systems using the flexible support of a full range of networks services over multiple infrastructure technologies.	Founded by Cisco, Bellcore and MCI Worldcom in 1998, and currently has 57 members.
Opensig and OpenArch	Begun by Columbia Unversity in 1996, the first OpenSig workshop was held to promote research on open network issues. In 1998 the IEEE Communications Society integrated OpenSig into its OpenArch conference.	-
IEEE P1520	IEEE established P1520 as a standardization group for programmable networks. The goal is to make the network as programmable as the PC through a set of standardized application programming interfaces (APIs).	-
The International Softswitch Consortium (ISC)	The ISC's objective is to promote open architectures, protocols, and APIs. The Consortium focuses on inter-operability and certification of voice and other real-time services.	Approximately 150 members.
Parlay	The purpose of the Parlay Group is to enable enterprises to control a range of network capabilities and access information within the network operator's domain.	AT&T, BT, Cegetel, Cisco, Ericsson, IBM, Lucent, Microsoft, Nortel Networks, Siemens and Ulticom BT. It is open to all interested parties.
IETF	The IETF has taken many initiatives to allow external control in the following areas: Media Gateway Control; Common Open Policy Service; General Switch Management Protocol; and Simple Network Management Protocol.	-

Source: Bjorkman et al. (2001)

In a more forward-looking paper, Peter Cellarius (1998) discusses the establishment of a Global Information Infrastructure (GII). The GII is actually a 'network of networks' which must function as one, with all the component networks working together and inter-operating. Cellarius points to a number of global trends leading towards the realization of the GII. For example, he argues that the opening of telecommunications markets through de-regulation, and the removal of barriers through free-trade agreements, will result in a significantly more competitive and expanding marketplace. Thus it can be expected that both the number of service providers and product suppliers will increase. He states that in an increasing number of cases, end-to-end services will no longer be provided by a single organization, nor will the totality of equipment needed for a service be supplied by a single manufacturer. This agrees with the trends discussed in the more recent paper by Bjorkman *et al.* (2001).

3.6 SUMMARY

This chapter highlights that much knowledge and technology lies within component suppliers in the infrastructure equipment industry. It is at their level that breakthrough scientific and technological innovation often takes place. The 'systems companies' – the large brand-name companies which manufacture equipment – also develop intellectual property. This intellectual property arises from their own R&D and is materialized within new configurations of components (such as ASICs) and, especially, in the design of the software that runs their manufactured hardware. This model particularly applies to the optical and wireless equipment industries, and to a lesser extent to the data networking/router manufacturers.

Another issue that these models reveal is that there is a general trend towards making equipment interoperable with that of other vendors. This is both a customer-driven trend – as service providers want to be able to offer 'best-of-breed' solutions – and a competitor-driven strategy, as smaller start-ups try to take market share from larger incumbent OEMs.

Implications for China's Telecom Equipment Industry

The industry trends described in this chapter have several implications for Chinese companies. The formation of a supplier base with advanced technological capabilities may be favorable for Chinese firms since it gives them the option to outsource component manufacturing. Thus Chinese companies may be able to concentrate on cultivating the core competencies of systems providers described above: software development, systems engineering, and ASICs development. The international industry survey has produced certain models that Chinese firms might be able to emulate. At least in the optics and Internet router segments, newer companies such as Sycamore Networks and Avici have tended to outsource as much as they can. At the same time, they have worked closely with component suppliers to develop the parts and modules they need to use. The advantage of this model has been that companies can concentrate on their core competencies while decreasing their time-to-market, which is critical in a fast-moving industry. It should also be noted that the scarcity of talent in the technology-intensive component sector that is felt in the U.S. (even though it has the universities that can produce it) may indicate that Chinese firms will have difficulty finding this talent at home. Even if it does exist, it will probably be attracted to the higher paying opportunities abroad (e.g. in Silicon Valley). Thus Chinese equipment companies may have no choice but to outsource parts of the value chain that require scarce specialist skills.

The fact that component suppliers are beginning to offer greater integration to their customers by moving into the supply of modules is also favorable to Chinese equipment vendors. If they choose to follow an outsourcing strategy, they may now be able to outsource a greater part of the value chain to companies such as JDS Uniphase. The advantages of this are, once again, better time-to-market, as well potentially higher quality products. Improved product quality derives from the fact that the assembly of certain components is a very high-precision process (especially in optics), thus outsourcing this to suppliers with the appropriate capabilities might be desirable.

The observation that most innovation generally lies within the high-tech suppliers of components and modules also has implications for Chinese companies. Many of these high-tech suppliers are increasingly on the look out for deals with companies that offer the promise of large markets for their products, and China is one such market[17]. Thus Chinese firms might be in a position to tap into the cutting edge technology within these firms and incorporate it into their products.

Lastly, a phenomenon that has been growing over recent years is the rising importance of contract manufacturers. These include companies such as Flextronics, Celestica and Jabil. They have been mostly involved in the outsourcing of manufacturing services in consumer electronics, but have been moving into other fields such as telecom infrastructure equipment (e.g. manufacturing routers and mobile subsystems). JDS Uniphase, as mentioned above, has been outsourcing some component manufacturing to Celestica. Although manufacturing issues are not central to the arguments of this thesis, the trend towards more contract manufacturing may have a potential impact on Chinese firms, as all the major electronics contract manufacturers have a presence in China. From a technology standpoint, contract manufacturers are repositories of manufacturing best practice, as well as out of necessity gaining a certain understanding of the technology they are being paid to manufacture[18]. Outsourcing to these companies, or *becoming* them may be alternative possibilities for Chinese equipment firms. In the former scenario, it would let Chinese firms concentrate on the technology and liberate resources from manufacturing. It has been discussed above that good manufacturing capabilities are critical for this industry. Chinese telecom infrastructure equipment vendors must therefore consider whether they are able to acquire these capabilities, or else outsource them to contract manufacturers.

[17] Interviewee #21.
[18] Professor Charles Fine, MIT Sloan School of Management (personal communication).

4 The Telecom Equipment Industry in China

4.1 *INTRODUCTION*

This chapter will begin by discussing the origins of China's telecom infrastructure equipment industry and its evolution to its present state. In a similar way to the preceding chapter, it will then attempt to draw a picture of the telecom equipment industry structure as it relates to China.

4.2 *THE DEVELOPMENT OF CHINA'S TELECOMMUNICATIONS TECHNOLOGY AND TELECOM INFRASTRUCTURE EQUIPMENT MARKET*

In the early 1980s China's communication infrastructure was weak. Furthermore, Chinese industry was unable to design or manufacture digital communications technologies such as SPC switches[1], which were at that time considered to be relatively advanced pieces of equipment. The government realized that the only way forward was to import foreign technologies and to assimilate, innovate and develop Chinese products on the basis of these technologies. In order to achieve this, the former Ministry of Posts & Telecommunications (MPT) drew up a three-pronged strategy: to import, to establish joint ventures with foreign counterparts and, in parallel, to conduct independent research and development (Peng 1999).

Early Joint Ventures in SPC Switches and the Emergence of China's Telecom Equipment Industry

In the early stages of China's opening to the West, the Chinese government encouraged foreign companies to establish joint ventures in China. Shanghai Bell Co., Ltd. became the first telecom equipment joint venture, manufacturing stored program controlled (SPC) switches, and was a result of a partnership between the China Posts and Telecommunications Industry Corporation (PTIC)[2] and the Bell Telephone Manufacturing (BTM) Company of Belgium (now part of Alcatel). Production at Shanghai Bell started in 1985 and, by 1998, it had produced a cumulative total of 33 million lines of its System-12 SPC switch – about a quarter of all switches sold in China. By then, its component localization rate had reached 74%, and that of software

[1] SPC signifies 'software program controlled'. SPC switches are the digital equivalent of the analogue cross-bar switches previously used in China. SPC switches can be programmed with a variety of 'intelligent' features according to customer needs.

[2] The Posts and Telecommunications Industrial Corporation (PTIC) was the industrial unit of the MPT set up at the start of the economic reforms to co-ordinate the activities of the MPT's 28 firms. It had previously undertaken equipment provision for the MPT's public network.

development 90%. Total sales revenues over the 1985-98 period reached 28.2 billion RMB (US$ 3.4 billion)[3].

Shanghai Bell spawned the growth of over eighty electronic products enterprises (Peng 1999). In addition, large-scale integrated circuit production technology was introduced by BTM (for use within the System-12 switches) through a joint venture with Shanghai Bell (itself a JV), called Shanghai Belling Microelectronic Manufacturing Co. Ltd.

Since 1990, several major joint ventures were establish in China for the purpose of producing switching technology. The largest of these are:

- Beijing International Switching System Corporation. Ltd. (BISC), in cooperation with Siemens of Germany;
- Tianjin NEC Electronics & Communications Industry Co. Ltd., with NEC of Japan;
- Lucent Technologies Qingdao Telecommunications Systems, Ltd., with Lucent Technologies of the U.S.;
- Guangdong-Nortel Telecommunications Systems Equipment Ltd., with Nortel of Canada;
- Jiangsu Fujitsu Telecommunications Technology Co. Ltd., with Fujitsu of Japan; and
- Nanjing Ericsson Communications Co. Ltd., with Ericsson of Sweden.

Chinese-Developed SPC Switches and the Birth of China's Leading Telecom Manufacturing Companies

The first Chinese-developed SPC switch, the HJD-04, was co-developed by the PTIC, the Information Engineering Institute of the People's Liberation Army, and the Luoyang Telephone Equipment Factory of the former MPT (Shen 1999). The relationship between these three organizations began in 1988, then in September 1993 the HJD-04 was approved by the MPT for use within its network, and in 1994 the HJD-04 No. 7 signaling system was successfully completed[4]. In order to commercialize this system, Julong (also known as Great Dragon Telecommunications Co. Ltd.) was founded in Beijing in March 1995. By 1998, sales of its system totaled 17 million lines, translating to a 17% share of the country's installed base of switches (Peng 1999).

Following in the footsteps of Julong's precursor and its HJD-04, Xi'an Datang Telecom Co. Ltd. was founded in 1993 and launched its own, self-developed, SP30 super digital SPC switch which passed production appraisal and obtained its network access license from the MPT in 1995. Zhongxing Telecom Ltd. (ZTE) of Shenzhen was also founded in 1993 and its own ZXJ10 digital SPC switch obtained its license in 1995. Huawei Technologies Co. Ltd. of Shenzhen also developed its own C&C08 small capacity digital SPC switch and high capacity switch which obtained their network licenses in 1994 and

[3] This joint venture is currently diversifying its product range into four main categories: System-12 SPC systems; mobile/data equipment; access network equipment; and multimedia terminals (Peng 1999).
[4] The No. 7 signaling system is the system specifically used for communication within the Chinese nationwide network.

1995, respectively. Lastly, Jinpeng Electronic Information Machine Co. Ltd was established in 1996, the same year in which its ETM-601 digital SPC switch obtained a network license (Peng 1999).

As of the end of 1997, there were 58 wholly owned Chinese companies manufacturing local switches and related products with an annual output of 12 million lines. In addition to the above companies, these also included Huaguang (producing the JSN-1), Legend (with its LEX-500), Song Da (HJD-1000), and the Beijing Telecom Equipment Factory (JSU2000-05) (U.S. Dept. of Commerce 1999).

Table 4.1 Local Switching Exchange Installed Base and Shipment by Model, 1996-1998

	Installed Base			**Shipments**		
Supplier	**1996**	**1997**	**1998**	**1996**	**1997**	**1998**
Alcatel	34,826,309	40,526,909	45,792,851	8,257,859	5,700,601	5,265,941
NEC	8,884,900	9,573,760	10,405,200	1,534,854	688,860	831,440
Fujitsu	10,254,241	11,749,241	13,460,077	1,413,451	1,495,000	1,710,837
Siemens	10,765,417	11,431,080	15,127,765	3,220,505	665,663	3,696,686
Ericsson	8,702,498	9,012,464	9,797,992	504,943	309,966	785,529
Nortel	7,595,000	8,602,500	9,817,500	2,195,000	1,007,500	1,215,000
Lucent	3,451,086	4,400,000	4,840,001	964,136	948,914	440,001
Huawei	3,669,426	6,084,508	10,502,316	1,849,823	2,415,082	4,417,808
Datang	1,430,000	2,090,909	2,714,286	830,000	660,909	623,377
Julong	3,300,000	5,162,400	8,192,600	1,800,000	1,862,400	3,030,200
Zhongxing	1,023,570	1,653,272	3,513,867	528,524	629,703	1,860,595
Other	485,554	592,857	682,898	389,165	139,403	129,681
TOTAL	**94,388,000**	**110,879,900**	**134,847,353**	**23,488,260**	**16,524,000**	**24,007,093**

Source: Pyramid Research 1999a

Today, Huawei, ZTE (Zhongxing), Datang and Julong form the core of China's domestic telecom equipment manufacturing industry as 'pure' Chinese companies. They have either grown out of state R&D and production facilities, or were independently established by entrepreneurs with government backing.

4.3 OVERVIEW OF CHINA'S FOUR LEADING EQUIPMENT MANUFACTURERS

The development of China's SPC switching market set the foundation for the growth and diversification of its telecom equipment industry. This saw the emergence of four leading domestic equipment firms: Huawei Technologies, ZTE, Datang Telecom Co., and Julong. As discussed above, these companies all have common origins in SPC switch manufacturing, although they are today establishing a more diversified range of telecom products. *Chapter 6* will focus on case studies of Huawei and ZTE.

Huawei Technologies

Huawei was set up in 1988 as a private company by Ren Zhengfei, a former officer in the People's Liberation Army. It is the only large Chinese telecom equipment vendor that is non state-owned. The company currently has over 15,000 employees, more than 80% of Huawei's staff have university degrees and have an average age of 27 years (Business Wire 2000b).

Huawei has 33 sales and marketing offices and 35 after-sales offices in China. Internationally, it has 35 branch offices in five continents, and its products have been introduced into over thirty countries including Africa (Algeria, Kenya), the Middle East (Yemen, Iraq), Asia (Laos, Hong Kong), Russia, Eastern Europe (Ukraine, Lithuania, Bulgaria) and Brazil.

In 2000, Huawei had recorded revenues of over US$ 2.65 billion, up from US$ 1.5 billion in 1999 and US$ 1.08 billion in 1998. Projected revenues for 2001 are expected to be in the order of US$ 5 billion[5].

Huawei has the highest sales revenue of the four companies. Although a latecomer in the telecom equipment manufacturing sector compared to Julong, it has rapidly risen to be the 'star' of the Chinese infrastructure equipment industry and has been developing technologies on several fronts.

ZTE Corporation (Zhongxing)

The precursor to ZTE was established in 1985 as the Zhongxing Semiconductor Co. Ltd. under the sponsorship of three organizations. These were the No. 691 Factory (under the former Ministry of Aerospace Industry, or MAI), the Changcheng Industrial Co. Ltd (Shenzhen office), and the Yunxing Electronic Trading Co. Ltd. In 1986 the company established its first research and development institute in Shenzhen. In 1990, Zhongxing Semiconductor obtained the certification and licensing from the former Ministry of Posts & Telecommunications (MPT) for its digital switch – the ZX500. This was followed by ZX500 (A) digital switch for C5 end offices which obtained a license in 1991.

In 1992, the company registered under the name Zhongxing-Weixian Telecom Equipment Co. Ltd. with the MAI as main shareholder and a capital of RMB 3 million. In 1993, the company developed its ZXJ2000 digital SPC switch and obtained a license from the MPT. In that year, Zhongxing-Weixian's switch succeeded in obtaining a 13% market share in rural areas.

In 1993, the Zhongxing Telecommunication Equipment Co., Ltd (ZTE) was registered under the sponsorship of the No. 691 Factory, Guanyu Industrial Co. Ltd. (Shenzhen), and Zhongxing-Weixian Telecommunication Equipment Co. Ltd. Thus ZTE was created with an initial capital of RMB 3 million provided by its three shareholders. In 1997, the

[5] Information obtained from Huawei website.

company listed on the Shenzhen Stock Exchange. 1997 was also the year in which ZTE commercialized its flagship product, the ZXJ10 Digital SPC switch which, together with its ZXA10 Access Server, were recognized as 'important new products' by the Ministry of Science and Technology (MST).

The company has long been a recipient of local and national government support. In 1994 ZTE was designated by the Shenzhen Government as a High-Tech Enterprised and received an AAA credit rating for bank loans. In 1996 it was designated by the State Council as one of the 300 key state-owned enterprises (this group was later increased to include 520 enterprises in total). In 1999, the company was chosen as a key enterprise to be supported by the State Economic and Trade Commission (SETC) and the Ministry of Information Industries (MII).

ZTE has 26 sales offices and the same number of service centers throughout China. All in all, more than 2,000 engineers and technicians are in charge of sales, commissioning and technical support. Over 40 marketing and engineering service centers have been established in Southeast Asia, South Asia, the Middle East, Eastern Europe, Africa, Latin America and the USA.

In 2000, ZTE claimed sales revenues amounting to RMB 10.2 billion (US$ 1.23 billion), with total assets of RMB 630 million (US$ 76 million). ZTE is considered to be in second place among Chinese telecom equipment manufacturers in terms of revenues and technology. It has also developed a series of successful products within several categories of communications technology, and is aggressively expanding internationally.

Datang Corporation

Xi'an Datang was formed in 1993 and in 1998 the company became known as Datang Corporation when it was listed on the Shanghai stock exchange. The company's corporate headquarters and primary manufacturing facilities are located in Xi'an, with other manufacturing sites being located in Shanghai and Shenzhen.

Datang's strategy is to invest heavily in R&D and works closely with research institutes and universities. Datang has an R&D center in Shanghai and, in addition, it cooperates on R&D with universities such as Dongnan University and Tsinghua University. Datang became the first local company to develop CDMA mobile communications technology.

Julong (Great Dragon Telecommunications)

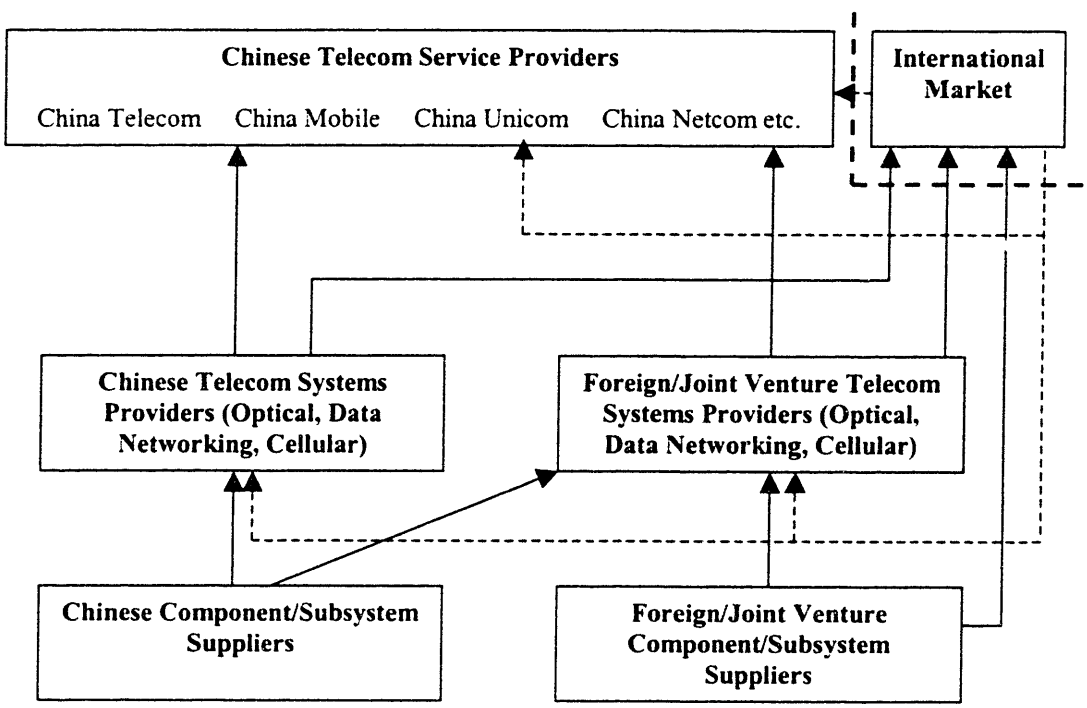
Julong was set up jointly in 1995 by the National Engineering Technology Research Center and the China Post and Telecommunication Industry Corporation (PTIC). Julong is in effect under the jurisdiction of the PTIC which functions as its holding company. The formation of Julong brought together nine separate HJD-04 manufacturers as well as some R&D institutes under one roof, and was an attempt by the Chinese government to consolidate the extremely fragmented switching industry[6].

Initially, Julong was very successful in the switching market and led the domestic industry. It has also diversified into mobile communications and other telecom technologies. However, in terms of technology and revenues, it is widely acknowledged that the company is now relegated to fourth place. Reasons given for this by former employees have been internal management issues (the company has a very complicated governance structure), and wasting of resources[7].

4.4 CHINA'S TELECOM INFRASTRUCTURE INDUSTRY: OPTICAL, DATA NETWORKING AND CELLULAR EQUIPMENT

Figure 4.1 summarizes the basic structure of the telecom equipment industry in China. Because of the difficulty in obtaining precise data on supply chain relationships, an aggregate view of the industry is presented encompassing the optical, wireless and data networking segments.

Figure 4.1 Aggregate View of China's Telecom Equipment Industry Structure



[6] By the mid-nineties, the HJD-04 technology had been widely disseminated and several small factories had sprouted to manufacture and sell this equipment (the government had a policy to spread the fruits of R&D behind HJD-04). Market entry by new competitors was done without consideration of efficient manufacturing scale nor the excess capacity already present. In addition, cut-throat competitive mentalities led to unsustainably low prices and unprofitable businesses.
[7] Interviewee #5.

China's Optical Telecommunications Equipment Industry

Domestic companies are now manufacturing optical transmission equipment and have developed WDM and DWDM products. However, it is proving difficult for domestic firms to emulate their success in the switching market within the optical transmission sector due to the higher technological complexity of this equipment. In 1999, foreign manufacturers still commanded 90% of the optical transmissions market at the national (backbone) level, and 70% at the provincial level, dominating with their SDH and WDM systems. Nevertheless, Chinese companies such as Huawei and the Wuhan Research Institute (WRI) have won some transmission contracts at the provincial and county level with their PDH and SDH-based transmission products (Pyramid Research 1999a). Foreign manufacturers are targeting the high-end of the market in order to stay ahead of local competition, and are importing the latest transmission technology and localizing production.

China is currently the third largest producer of optical cable in the world, with over 120 firms producing optical cable and an annual production of abut 300 thousand kilometers (and a capacity to produce 500 thousand kilometers of cable per year). Chinese producers claim 60% market share, however domestically produced optical cable is of a conventional and relatively simple type. Thus over 90% of special products, such as marine cable, need to be imported (AI Consulting 2000a).

Wuhan's 'Optics Valley': Fertile Ground for the Growth of an Indigenous Components Industry

A key research, development, and production area for fiber-optic telecommunications components is located in central China in the Wuhan East Lake High Tech Development Zone (HTDZ)[8]. This zone is part of an area of universities and enterprises the Chinese government calls the "optics valley of China". The largest of several emerging optics technology centers in China, this zone was originally established in 1991 to further the research and development of optoelectronics, bioengineering, and software in China (Richards 2000).

One of the key institutions within the Wuhan HTDZ is the Huazhong University of Science and Technology, which established a national gas and solid-state laser lab in 1980. In the 1990s, the focus of the lab turned to fiber-optic communications as the market potential of this technology became evident. In 1994 the first national optical telecom research center was established, and a national photon-electron technology center was built in 1999. As a consequence, the university's research in these areas have given it a well-known reputation in laser technology.

Today, the Wuhan East Lake HTDZ includes 23 universities, 56 research institutes, and 59 optoelectronics-related companies. Among the most prominent of these enterprises is the *Wuhan Research Institute of Posts & Telecommunications* (WRI), which is an umbrella organization encompassing several institutes and companies. These include the

[8] By 2005, this zone is planned to reach 50 square kilometers.

Wuhan Telecommunications Devices Corp. (a partner of Corning Lasertron), the Solid-State Device Institute, and Fiberhome Optic Communication Corp. WRI developed China's first 2.5 Gigabit(Gbit)/sec SDH system and also deployed China's first 4x2.5Gbit/sec DWDM system in the Haiko-Sanya fiber-optic route in April 1998.

Within close proximity to the East Lake HTDZ is the Yangtze Optical Fiber & Cable Co. Ltd. (YOFC), the largest fiber and cable producer in China, owned by Draka/NC Cables. Other companies in the area include Changjiang Ericsson Co. and Wuhan NEC Optical Fiber Communications Industry Co. Ltd. Annual production of optical fiber within the 'optics valley' has reached 2.5 million kilometers of cable.

Like other high-tech development zones in China, enterprises in the Wuhan East Lake HTDZ benefit from state-level preferential policies such as reduced income tax of 15%, exemption from municipal level fees, and lower land charges. Furthermore, the local authority – the Administrative Committee of the Wuhan East Lake HTDZ – is actively pursuing foreign and domestic investment with a fair amount of success[9].

Guangdong's 'Photon Valley'

The Provincial Government of Guangdong is encouraging the growth of an indigenous optoelectronics industry in Southern China. As part of this initiative, the local government has signed a memorandum of understanding with Lucent Technologies (China) for the U.S. company to provide advisory support in establishing this industry[10]. Lucent has separately set up a joint R&D lab with Huawei in Shenzhen to focus on developing optical components for the Chinese company's products[11].

Participants in China's Optical Industry

There are about twenty manufacturers of PDH and SDH optical equipment in China, seven of which are joint ventures with the major foreign companies – Lucent, Fujitsu, NEC, Alcatel, Nokia, Siemens and Ericsson. The largest manufacturers are Lucent Shanghai Transmission Equipment Co., Nanjing Fujitsu Transmission Equipment Co., Wuhan NEC Fiberoptic Telecom Equipment Co., and Huawei Technologies (Richards 2000). Foreign suppliers still command over 90% share of the transmission market at the national (backbone) level, and 70% at the provincial level, dominating with their optical SDH and WDM systems[12] (Pyramid 1999a). *Tables 4.2* and *4.3* list the optical systems and components/subsystems providers in China.

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[9] The China Construction Bank recently authorized its Hubei branch to grant loans of up to 8 billion yuan (US $964 billion) to the Wuhan optics valley. The agreement represents 40% of the gross investment intended for the optics valley. Separately, the Hubei branch granted a loan of 2 billion yuan (US $241 million) to a group of high-tech enterprises in the Wuhan HTDZ, of which 600 million yuan (US $72 million) will be used to invest in optoelectronic information companies (Richards 2000).

[10] Information obtained from Huawei's website (www.huawei.com).

[11] See *Chapter 6*.

[12] China Telecom's main WDM suppliers were WRI, NEC, Lucent and Alcatel at the national (backbone) network (Pyramid Research 1999a).

Table 4.2 Optical Communication Systems Providers

Company	Owner-ship*	Products Made
Huawei	C	DWDM
Zhongxing (ZTE)	C	DWDM
Wuhan Research Institute (WRI)	C	DWDM
Nanjing Fujitsu Telecom Equipment Co.	JV	SDH/PDH fiber-optic transmission systems
Lucent Technologies Shanghai	JV	Optical digital transmission systems, including SDH
Wuhan NEC Optical Fiber Communications Co.	JV	SDH/PDH fiber-optic transmission systems
Shenyang Nortel	JV	SDH transmission systems

* C = Chinese (state-owned or private); F = Foreign (wholly-owned); JV = Chinese-Foreign joint venture

Source: PTIC, Pyramid Reseach

Table 4.3 ***Components and Sub-system Suppliers for the Optical Equipment Industry***

Company	Ownership*	Products Made	Customer
Component Suppliers			
Fujian Casix Laser (acquired by JDS Uniphase)	F	Fiber-optic component processing and assembly, optical design, fabrication and coating. Advanced crystal growth.	JDS Uniphase subsidiary
Luminent Inc.	F	Assembly and testing of passive optical components (manufactured in Taiwan)	Cisco, Marconi, JDS Uniphase
PTIC Houma Comm. Cable Co	C	Optical cable	-
Shanghai Posts & Telecom Equipment Co. (PTIC)	C	Optical transmission equipment	-
Chengdu Cable Co. (PTIC)	C	Optic fiber, optical cable	-
Chongqing Communications Equipment Co. (PTIC)	C	Optic transmission equipment	-
Lucent Beijing Optical Cable Co	JV	Optical Cable	Lucent
Lucent Technologies Shanghai Fiber Optic Co.	JV	Fiber optic products	Lucent
Siemens Communications Systems	JV	'Last mile' products for fiber-optic networks.	Siemens
Siemens Optical Fiber Cable Co.	JV	Entire range of fiber-optical cables, including terrestrial and fiber ribbon cables	Siemens
Wuhan Institute of Posts & Telecom Science	C	Optical cable	-
Foshan City Zhongbao Enterprise Group Co.	C	Optical fiber cable	-
Shanghai Huaxin Wire and Cable	C	Optical fiber cable	-
Zhejiang Tianyi Group Co.	C	Optical fiber cable	-
Yangtze Optical Fiber and Cable Co	JV	Optical fiber	
Sub-system Suppliers			
ADC Telecom Nanjing	F	Fiber optical distribution systems, optical components, optical subsystems for the China and international market.	-
Oplink Communications Shanghai, Beijing and Zhuhai	F	Optical components and modules	-
Zhejian Eastcom Comm. Co (PTIC)	C	Wireless optical access network	-
Guangzhou P&T Equip. Co. (PTIC)	C	Optic transmission systems	-
Beijing Optical Comm. Technology Co. (PTIC)	C	SDH optical fiber transmission system	-
Guangzhou Nanfang Transmission Systems	JV	PDH and SDH fiber-optic transmission systems	Siemens
Alcatel Chengdu Communictions Systems Co	JV	PDH/SDH fiber-optic transmission systems	Alcatel
Wuhan Yangtze Ericsson	JV	SDH Optical equipment	Ericsson
Lucent Shanghai Optical Fiber Co.	JV	SDH Transmission equipment, access network equipment	Lucent
Shenyang Nortel	JV	Development, marketing and production of SDH transmission systems	Nortel

* C = Chinese (state-owned or private); F = Foreign (wholly-owned); JV = Chinese-Foreign joint venture

Source: PTIC, Pyramid Research, various industry newswires

Fujian Casix and JDS Uniphase

In 2000, JDS Uniphase[13] announced that it had acquired Fujian Casix Laser, a Chinese optical components group (PR Newswire 2000b). Fujian Casix Laser was a profitable operation previously owned by FEH, a private holding company controlled by the Fujian provincial government. Casix, which is ISO 9001 certified, now operates as a wholly-owned subsidiary of JDS Uniphase and employs 750 staff, primarily at its principal offices in Fuzhou, Fujian.

Fujian Casix supplies crystals, fiber-optic components and optics for telecom networks. The company's key technologies include fiber-optic component processing and assembly as well as optical design, fabrication, and coating. Fujian Casix also engages in advance crystal growth and processing[14]. The advanced materials obtained by JDS through this acquisition are used to make interlevers[15]. This is a prized technology in the components segment which JDS claims will give it the ability to become more competitive in the interlever marketplace.

> *"The acquisition represents an important move in our global manufacturing strategy. The Casix management team has demonstrated strong leadership skills which we expect will serve us well for our first venture in China. We believe that the advanced materials science expertise at Casix is a key to new generations of components for optical networks."*
>
> *Jozef Straus*
> *JDS Uniphase Co-Chairman, President and Chief Operating Officer*

The acquisition is an indication that JDS Uniphase is betting on a booming fiber-optic market in China. It also provides the U.S. supplier with a strategic manufacturing location in a low-wage region and, according to company executives, will serve as a platform for the global market. According to statements made by the company, JDS is planning additional investments to increase Fujian Casix Laser's manufacturing capacity.

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13 See *Chapter 3*.

14 The crystals produced or processed by Casix include YVO4 and Lithium Niobate, both of which are used in the production of various advanced fiber optic components. Fiber optic components produced by Casix include basic assemblies such as fiber tips ("pigtails") and jumpers, and components such as collimators, isolators and polarization beam splitters. Casix also performs significant production and processing of basic optical elements such as etalons, waveplates, prisms, isolator cores, windows and filters, and the application of anti-reflective coatings to various optical elements.

15 Interlevers are devices designed to, for example, separate a 40-channel fiber optic system with 50-Gbyte spacing into two streams with 20 channels each and with 100-Gbyte spacing. The advantage is that it alleviates the need for multiplexing.

Challenges for Domestic Firms

According to Information Gatekeepers Inc. (IGI), a Boston-based consulting firm, optical technology development in China lags about one year behind that of industry leaders. Although it is technologically advanced, it is not at the cutting edge. For this reason domestic manufacturers are trying to export to markets that are more price-sensitive such as Russia, Southeast Asia, India and Eastern Europe.

China's Data Networking Industry

Foreign manufacturers have captured most of the data networking equipment market in China (AI Consulting 2000c). China's local manufacturing industry is behind in remote-access servers, and limited mainly to low-end routers (such as Cisco's 2500 service routers). Local vendors also have a long way to go to refine their ATM switching technology and, although they already have the switching fiber and ports, they have yet to master the software technology. It has been argued that it is difficult for local vendors to catch up as quickly in the data networking equipment market, compared to the switching and transmission equipment markets, because the technology is changing so fast. However, local ATM vendors are making aggressive attempts to lay a claim in this market (Pyramid 1999a). *Table 4.4* lists the major domestic participants in China's data networking industry.

Table 4.4 Data Networking Systems and Component/Module Suppliers

Company	Owner-ship*	Products Made
Systems and Equipment Providers		
Centel Telecom Co. (PTIC)	C	Access routers, ISDN terminals
Gao Hong (under the MII)	C	ATM switch (CS-1000). Was the first domestic supplier to develop an ATM switch in 1998 with the China Academy of Telecom Technology.
Huawei	C	Core, backbone, modular, branch and SOHO routers, ethernet switches, access servers
Shanghai Bell joint venture with BUPT**	JV	Developing an ATM switch (with less than 10 switch nodes)
Shanghai Radio Comm. Equipment Co. (PTIC)	C	IP switching systems
ZTE	C	Terabit IP router, access server, ISDN router, backbone switch, access switch, service access equipment, access multiplexer.
Component and Module Providers		
Nanjing P&T Equipment Co (PTIC)	C	Data communications products such as CDPD, POS, ISDN adapter, desktop video conference

* C = Chinese (state-owned or private); F = Foreign (wholly-owned); JV = Chinese-Foreign joint venture

** Beijing University of Posts & Telecommunications

Source: PTIC, Pyramid Research

Foreign networking firms such as Cisco and Juniper do not seem to have a significant local manufacturing capability in routers, with most of their sales coming in the form of imports (SG Cowen, 2001).

China's Mobile Equipment Industry

China began to import mobile communications equipment and provide mobile services in 1987, and adopted the GSM mobile standard in 1994. In 1992, Datang Telecom Technology Group began undertaking R&D on mobile communications equipment and in 1996 produced the first domestic GSM mobile communications system. In cooperation with Eastcom, Datang launched a mobile communications system incorporating it own intellectual property in 1998 (the M30-G). Currently, Datang is able to provide a complete range of mobile communications solutions, including base station controllers and base stations (Peng 1999). In 1998, Huawei Technologies installed it first self-developed GSM mobile communications system, the M900 and the dual band M900/M1800 systems (U.S. Dept. of Commerce 1999). In June 2000, ZTE unveiled its first complete CDMA system – including base stations, switches, and handsets – which is ready for commercial development (AI Consulting 2000c). ZTE can also provide a dual band GSM900/1800 system (U.S. Dept. of Commerce 1999). At present, Datang, Huawei, ZTE and Jinpeng have obtained access licenses from the MII for their mobile communications systems.

Participants in China's Mobile Telecom Equipment Industry

China has over 100 telecommunications plants producing mobile system parts and equipment, the major Chinese GSM producers being Datang, ZTE, Huawei and Jinpeng. These domestic firms compete with the leading foreign companies (and their JVs) who currently dominate the market in mobile switches and base station equipment. These include Tianjin Motorola; Hangzhou Eastern Telecommunications Company (or EastCom, a Motorola joint venture); Beijing Nokia; Beijing Ericsson; Beijing Matsushita; Wuhan NEC; Shanghai Siemens; and Shenzhen Philips (U.S. Dept. of Commerce 1999).

In 1999, the percentage of revenues that went to domestic players in mobile base stations, handsets, and switches stood at 2%, 3% and 4%, respectively (Pyramid Research 1999b)

Tables 4.5 and *4.6* outline a selection of mobile systems providers, and sub-systems and components suppliers. Note that many of the foreign JVs are classified under 'sub-systems' suppliers as they provide these to their foreign parent company which is itself the branded 'system' provider.

Table 4.5 Mobile Infrastructure Systems Providers

Company	Ownership*	Products Made
Huawei	C	GSM mobile communication system
Zhongxing (ZTE)	C	GSM and CDMA mobile communication system, ZXC10.
Datang	C	GSM mobile communication system
Jinpeng	C	GSM mobile communication system
Beijing Ericsson	JV	GSM mobile communication system
Hangzhou Motorola	JV	CDMA system infrastructure equipment and services
Beijing Matsushita	JV	GSM systems
Xi'an Fujitsu Telecom Equipment Co.	JV	Radio and mobile communications systems
Xi'an NEC Radio Comm. Equipment Co.	JV	SDH based large-capacity microwave communications systems
Guilin NEC Radio Communications Co.	JV	SDH based microwave systems
Guangdong Nortel Telecom Equipment Co.	JV	Design, engineering, manufacturing and installation services of advanced switching equipment, GSM900/1800 and CDMA wireless systems.

* C = Chinese (state-owned or private); F = Foreign (wholly-owned); JV = Chinese-Foreign joint venture

Source: PTIC, Pyramid Research, Nortel

Table 4.6 Components and Sub-system Suppliers for the Mobile Communications Industry

Company	Owner-ship*	Products Made	Customer
Component Suppliers			
PTIC Xi'an Comm. Equipment Factory	C	Wireless frequency amplifier, microwave antenna, mobile station antenna	-
PTIC Jingdezhen Comm. Equipment Factory	C	Fixed wireless access equipment	-
PTIC Guilin Telecom Equipment Factory	C	Microwave equipment	-
Shenzhen Kangxun Telecom Co. Ltd. (ZTE)	C	Wireless access system components	ZTE
Sub-system Suppliers			
Huawei	C	GSM switching system	Motorola
ZTE	C	CDMA switching system	-
Zhejian Eastcom Comm. Co	C	GSM communications system equipment	-
Beijing Taili Technology Development Co. (PTIC)	C	Mobile communications equipment	-
Guangdong Nortel Telecom Switching Equipment Co.	JV	DMS Super Mode products and digital access for CDMA	Nortel
Siemens Shanghai Mobile Communications	JV	Sets of GSM mobile equipment, including base station systems and mobile terminals. Adapted BISC's EWSD switches for cellular applications.	Siemens
Siemens Communications Systems	JV	'Last mile' products for radio communications networks.	Siemens
Beijing Ericsson Communications Systems	JV	MD110 PBX and AXE local and mobile exchanges	Ericsson
Beijing Ericsson Mobile Communications	JV	GSM/TACS base stations, handsets, mobile network design and implementation	Ericsson
Dalian Ericsson Comm.	JV	CO switch and cellular system support for NE China	Ericsson
Shanghai Bell – Alcatel Mobile Communications	JV	GSM base stations, control equipment, mobile switches	Alcatel
Alcatel Chongqing	JV	DMW technology with Alcatel Telettra for 1.5 GHz systems	Alcatel
Alcatel (Beijing) Transmission Systems Co.	JV	Small, medium and high-capacity DMW systems, including STM-1 SDH microwave	Alcatel
Nokia (Suzhou) Telecom Co	F	GSM base stations and cellular network transmission products	Nokia
Beijing Nokia Hang Xing Telecommunications Co	JV	Mobile digital switching centers, base station controllers and fixed digital switches	Nokia
Beijing Nokia Mobile Telecommunications	JV	GSM digital cellular systems	Nokia

* C = Chinese (state-owned or private); F = Foreign (wholly-owned); JV = Chinese-Foreign joint venture

Source: PTIC, Pyramid Research

Challenges for Domestic Firms

Despite technological advances by Chinese competition and official stipulations that state telecom service providers 'buy local', foreign mobile equipment makers have managed to avoid significant loss of market share in high value-added products (Kynge 1999). Two reasons that have been cited for this are, firstly, that companies such as Nokia and Ericsson have made a great effort to localize their production, and now seem to qualify in the eyes of Chinese regulators as "local". Secondly, foreign vendors have a mixture of superior quality, track record and entrenched market position playing in their favor. Indeed, the market for cellular systems remains heavily determined by relationships developed early between PTAs and foreign vendors, with the PTAs particularly preferring to hand out big contracts to companies they already know and trust (Pyramid Research 1999b).

Chinese-Foreign Joint Ventures

As can be observed from *Tables 4.2-4.6* above, a major aspect of the domestic industry structure is the presence of numerous foreign joint ventures. Joint ventures are a common mechanism for foreign direct investment (FDI) in a country. Foreign companies often seek local partners who have an intimate knowledge of the market as well as useful links with government officials, suppliers, etc. which are very valuable when initially operating in a new environment. Nevertheless, the very large number of JVs and near-total absence of wholly-owned foreign enterprises (WOFEs), another form of FDI, can be attributed to the government policy of "technology for market share". This policy pressured foreign companies wishing to set up operations in China not to establish WOFEs, but rather to form JVs with local players in a bid to encourage the transfer of technologies to domestic companies.

In both the optical and cellular communications sectors, foreign JV equipment manufacturers outnumber the domestic manufacturers. Furthermore, although many Chinese firms have been listed as components and subsystems providers, it is safe to assume that the foreign JVs in this category collectively have a higher volume of production of higher-technology components than their Chinese counterparts (who tend to manufacture low-tech parts). Given the fact that foreign firms currently dominate the telecom infrastructure equipment industry in China, and that foreign companies are present through their joint ventures, the group of JVs describe above represents a substantial segment of the Chinese equipment industry among themselves (at least in the higher technology segments of optics, networking and cellular equipment).

Typically, JV relationships in this sector are of long duration[16]. Although extensive data could not be obtained, it seems that JV contracts negotiated with the Chinese government extend for long periods of time. For example the initial contract for Shanghai Bell, a JV with Alcatel, was for a duration of 15 years. This was later extended for another 20 years, lasting until the year 2014 (Shen 1999). Another example of the long life of JVs in this sector is provided by Nortel, who's three telecom equipment joint ventures in China were established in 1988, 1994 and 1995 and are still presently operating.

Another feature of these JVs is that majority foreign ownership seems to be the norm for many companies. Nortel, for example, claims to have ownership shares of between 55% and 90% among its Chinese JVs. Reasons for this included the protection of its intellectual property and the fact that only majority-owned JVs would be able to qualify for Nortel's direct sourcing capabilities and transfer pricing arrangements[17]. *Appendix 3* contains a list of domestic and JV telecom equipment producers from which the above tables were derived. It shows that many foreign companies typically have majority ownership of their joint ventures, particularly when they involve the production of relatively high tech equipment. Furthermore, even when foreign ownership falls below 50% the foreign company often reserves the ability to make the major management decisions concerning the JV[18].

4.5 SUMMARY

The preceding account of China's evolving telecom equipment industry indicates that the sector has evolved substantially over the past decade. In certain cases, such as in optical components, China seems to have developed a critical mass of expertise – to the extent that foreign companies have bought Chinese ones in order to access their technology. DWDM optical communication and Internet router equipment are two fledgling technologies that are also being rapidly developed (and are very lucrative segments of the infrastructure equipment market). In fact, a trend has been observed in which the technological development cycle for Chinese manufacturers is getting shorter, as illustrated in *Figure 4.2*.

In response to the decreasing lead time between product introduction by foreign vendors and the emergence of locally-produced equivalents, foreign manufacturers are quickening the pace of technological innovation and product diversification. In fact, a paper by Li *et al.* (2000) describes that, in order to stay ahead in China, foreign firms are using their technological leadership to feed the latest products to the Chinese market. Only in this way, it is argued, will they maintain a competitive advantage. Meanwhile, domestic firms also benefit by being exposed to the most up-to-date technology, which they can attempt to reverse-engineer.

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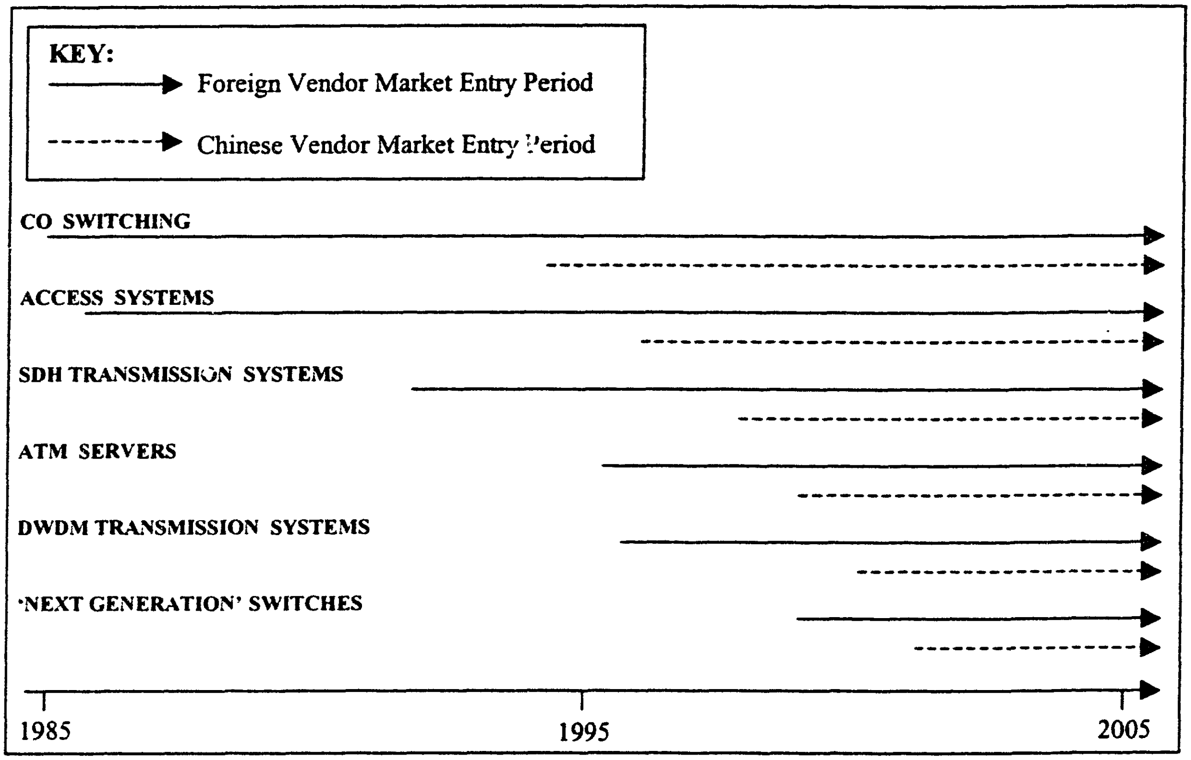
[16] This may at least be partly explained by the government policies encouraging technology transfer. It would be unseemly for a foreign company to dissolve a JV before the end of a contract, and they are useful vehicles for foreign firms to demonstrate their commitment to China by advertising their localization initiatives.

[17] Interviewee #10.

[18] Interviewee #9.

Figure 4.2 Indigenous Technology Development Cycle



Source: Pyramid Research (1999a)

With respect to the industry structure, the market concentration of *domestic* companies that are systems-level providers seems to be relatively high. The largest, technologically diversified, domestic players number four in total. These are Huawei, ZTE, Datang and Julong. Within the specific fields of telecom equipment (optics, data networking and wireless), some other important domestic niche players arise that tend to specialize in these segments (such as the WRI in optical transmission, and Jinpeng in wireless communication).

When broadening the picture to include foreign-invested enterprises, one notices the large presence of Chinese-foreign JVs across several communications segments. This is not surprising, given the fact that foreign companies tend to dominate the market in many of these areas, and that the world's major telecom equipment manufacturers vie with each other to establish a presence in China. However, whereas foreign companies may have a presence in several communications segments, their JVs (each of which is a separate legal entity) tend to focus on a particular area of the communications market. Therefore these JV companies swell the ranks of enterprises involved in specific areas of communications which, taken segment by segment, have a large number of players and thus a low market concentration.

5 Chinese Government Policy and Regulatory Structure

5.1 Introduction

A primary goal of the Chinese government has been to be less dependent on telecom imports. In order to achieve this, the former MPT stated that the government's strategy for the telecommunications industry would entail a three step process: 1) import of technologies; 2) establishment of joint ventures with companies that are leading the world in specific areas; and 3) development of telecommunications products with Chinese intellectual property rights. China also hopes to export its own telecom products to other countries after meeting its domestic demand (U.S. Dept. of Commerce 1999).

This chapter will begin by reviewing the principal players in the policy-making process. This will be followed by a discussion of the various policies that the Chinese government has put in place to build up the country's telecommunications equipment sector.

5.2 Government Institutions and Regulatory Structure

The Ministry of Information Industry

In March 1998, the Ninth National People's Congress (NPC) ratified a wide-ranging restructuring of China' state bureaucracy. Among others, this saw the merger of three ministries – the Ministry of Posts and Telecommunications (MPT), Ministry of Electronics Industry (MEI) and the Ministry of Radio, Film and Television (MRFT) – into a so-called 'super ministry', the Ministry of Information Industry (MII).

The MII's responsibilities are for drafting the plan, policy and regulation for the entire information industrial sector. This encompasses the policy power previously possessed by the MPT and the MEI; the network regulatory power over program content, broadcasting networks and private satellite networks; the overall planning of all types of public and private communications networks; the reasonable allocation of communications resources (including frequency allocation and land rights); and the guarantee of information security (Pyramid Research 1999b). A government statement identifies the major responsibilities of the MII as:

- Revitalizing the electronic and information technology manufacturing sector, the telecommunications sector, and the software sector.
- Promoting the 'informationalization' of the national economy and social services.
- Making plans, policies and regulations for the information industry.

- Conducting overall planning and regulation for the national backbone communications networks (including both local and long distance telecommunications networks), the radio and television broadcasting networks (including both cable and non-cable TV networks), as well as the private networks of the military and other sectors.
- Allocating resources to avoid duplicative construction and safeguarding information security.

Other Important Government Bodies with a Stake in the Telecommunications Sector

Other institutions that are key players in China's telecom sector include:

The State Council

The State Council is a cabinet-level group with ultimate decision-making authority on key policy issues in China. It also formulates laws and issues policies regarding any macro-level policy decisions, such as the direction of China's five-year plans for telecommunications development.

The State Development and Planning Commission (SDPC)

Formerly the State Planning Commission (SPC), the SDPC is the overseer of China's various economic plans, including the five-year plans. Its current role is to review and sanction industrial and other economic reforms.

The State Economic and Trade Commission (SETC)

The May 1998 announcement that created the MII stated that it would work closely with the SETC to set policies for China's information industry, including policies regarding the introduction of foreign investment and foreign technologies, and the elaboration of strategic development plans. Together with the SDPC, the SETC claims responsibility for such tasks as outlining industrial policy and deciding in which areas foreign-investment is to be encouraged or discouraged.

5.3 IMPORT SUBSTITUTION AND TECHNOLOGY TRANSFER POLICIES

The Chinese government is determined to accelerate the localization of telecommunications technology, both by encouraging the development of local players and by forcing companies to localize production. In order to do this, it has adopted a range of policies which fall under the broad umbrella of 'import substitution' policies, as follows:

- *"Buy local" policies.* These policies encourage telecom operators to purchase equipment manufactured by local industry, or make it harder to purchase imported equipment. This has the double advantage of improving demand conditions for local industry as well as encouraging foreign companies to localize in order to pass for a "local" company.

- *Localization policies.* These include a variety of policies that directly require or encourage foreign companies to localize production, management and/or research & development. These policies are often embodied in regulations which make localization a precondition for doing business in China, and are often tied to the establishment of joint ventures as a vehicle for doing so.

- *Trade policies for import substitution.* These policies target the reduction of foreign imports by a variety of means, including the imposition of quotas, higher tariffs, or the granting of special licenses for the introduction and use of technologies within China.

It must be noted that some of the policies under the first and third categories are commonly referred to 'non-tariff barriers to trade' in the jargon of the World Trade Organization (WTO). Given China's intention to join the WTO, it will have to address these issues which are illegal under the GATT[1] treaty.

"Buy Local" Policies

Part of the MII's strategy to strengthen domestic telecoms equipment manufacturers is to encourage PTAs to "buy local" when possible. Although there are no written laws specifying quotas or stipulating that local products must be purchased, the government's preference for operators to purchase locally-manufactured equipment is no secret[2]. However, the definition of "local" is vague since, depending on the MII's requirement at any given moment, it can mean goods purchased from Sino-foreign JVs or from purely domestic manufacturers only (Pyramid Research 1999a). For example, when domestic production of SPC switches was first introduced by Shanghai Bell (a joint venture), the former MPT decreed that its product – System-12 – was one of the principal switching systems for use in the Chinese telecommunications network (Shen 1999). Only cutting-edge products which are unavailable in China (e.g. high-end data switching gear) are imported by China Telecom's PTAs with the central government's blessing (Pyramid Research 1999a). The MII has been fairly explicit that equipment produced by 'favored sons' should be incorporated into China Telecom's network. It is therefore likely that domestic companies will receive preferential treatment in the awarding of 3G digital cellular networks (Pyramid Research 1999b).

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[1] General Agreement on Tariffs and Trade.

[2] However, PTAs that generate healthy revenues wield a high degree of autonomy in procurement decisions. PTAs with low revenues, such as those in inland provinces, depend on the MII for cash to build networks and thus must accept the MII's procurement decisions.

To encourage the purchasing of Chinese-made equipment, the MPT/MII organized three local vendor-carrier meeting since 1996, demanding the carriers China Telecom, China Unicom and the PTAs to give priority to domestic products so as to support the development of China's telecom manufacturing industry. The 1996 and 1997 meeting focused on fixed line SPC switching equipment[3]. Due to the success of the previous two meetings, a third coordination meeting was held in 1998 which centered on domestic cellular systems, in particular the purchasing of mobile switches, base stations and handsets[4] (U.S. Dept. of Commerce 1999). Thus, through the MII (and formerly the MPT), China's central government actively promoted the domestic fixed-line switching and mobile communications industries.

Documents circulated by the State Council and the MII during the 1998 coordination meeting outline certain policies for promoting the purchase of domestically-made equipment (see *Appendix 4*). These include stipulations that Chinese telecom operators should give priority to domestic products when the price and quality are similar to imported products; and that, once products with Chinese intellectual property reach the "network access standard", a procurement policy of giving priority to these products should be adopted.

Countering central government's push for 'buying local' is the concern of provincial PTAs to generate revenues as quickly as possible, particularly in rolling out cellular services. Thus, at least in the near future, PTAs are rushing to purchase as much equipment as possible from foreign companies to increase their capacities before they face being squeezed by the center to purchase more locally (Pyramid Research 1999b). Although this may not be a long-run problem, it probably aggravates the future challenge to domestic manufacturers of overcoming the network effects of an installed base of foreign equipment.

It is also important to note that the central government's "buy local" policy does not necessarily limit the PTAs purchasing decisions since they still aim at incorporating 'world class' standards into their networks – and hold local companies to these standards (Pyramid 1999a). For example, although domestic companies are very competitive in the fixed line switching market, China's operators still purchase long-distance transmission equipment from foreign companies as they believe these to be of better quality.

On the other hand, provincial network operators still like to buy from domestic companies for pragmatic reasons. They view them as companies which have a long-term

[3] During the 1996 meeting, representatives from China PTIC, Julong, Datang, Zhongxing and Huawei, among others, met with officials from over 30 PTAs. Orders for purchasing over 5 million lines were signed, and actual orders surpassed 7 million lines. The 1997 meeting included the same players plus Jinpeng, and resulting in purchasing agreements for 17 million lines over two years (Peng 1999).

[4] The 1998 national coordination meeting on mobile communications systems and equipment was held in Beijing. Participants included China Telecom, China Unicom, the PTAs, Datang, Eastcom, Huawei, Jinpeng, Zhongxing, Julong, Shanghai Bell Alcatel Mobile Communications Systems Co. Ltd., Beijing Nokia Mobile Communications Co. Ltd., Nanjing Ericsson Communications Co. Ltd., and Siemens Shanghai Mobile Communications Co. LTd. At this meeting, purchasing agreements for about 7 million lines of mobile switches and 700,000 channels of base station equipment were concluded (Peng 1999).

commitment, entrenched interests in China, and a firm understanding of Chinese network requirements. Domestic companies build their equipment with one main client in mind – China Telecom – and therefore are closer to the market, offer Chinese standard compatibility, and adhere to Chinese software protocols (Pyramid Research 1999a).

As a result of the MII's 'buy local' efforts, it claims that it has successfully helped Chinese fixed line switch manufacturers to gradually dominate the market (see *Section 4.2* for data on domestic producers' sales).

Government-Sponsored Vendor Financing and Financial Incentives for Equipment Buyers

In conjunction with its "buy local" policy, the central government encouraged commercial banks to offer loans to domestic vendors or directly to PTAs in order to stimulate demand for locally-produced technologies[5] (U.S. Dept. of Commerce 1999). This type of government-subsidized vendor financing is engineered to make domestic firms more competitive.

For example, in the case of SPC switching equipment, financial organizations such as the People's Bank of China and the Duty & Tax Committee of the State Council began to support domestic producers by offering purchaser loans and reduced sales taxes. Presently, Julong, Datang, ZTE and Huawei all benefit from purchaser loans from the Commercial Bank of China (Peng 1999).

The government has introduced tax concessions to operators for upgrading network equipment, and the MII has encouraged PTAs to continuously develop their networks in terms of capacity, transmission speeds, and technology (Pyramid Research 1999a). This encourages domestic manufacturers to develop and introduce more 'intelligent' and higher-capacity equipment by promoting the market for such products. Furthermore, the government is promoting Chinese-manufactured exports by offering tax breaks and other financial incentives (Pyramid Research 1999a).

Localization of Production and Technology

The Government views the development of the high-technology industry with a long-term perspective. Job creation is no longer the priority in China's localization drive in this sector, rather, skills development and intellectual capital are more important (Pyramid Research 1999a). The government's main requirement for foreign equipment manufacturers is that they demonstrate their commitment to China through technology transfers to local partners. To ensure this, Chinese-foreign JVs are subject to

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[5] During 1998-1999, state banks extended credit packages to domestic companies to help them finance equipment deals nationwide. For example, in 1998 Datang secured a nearly $ 1 billion (RBM 8 bn) credit from the Industrial and Commercial Bank of China (ICBC), over 85% of which was earmarked for facilitating supplier credit for customers through 2000. The China Construction Bank and ICBC jointly put together a package worth over $ 720 million (RMB 6 bn) to fund equipment sales in 1998-99.

performance requirements which they must agree to in order to gain approval for establishment. The most relevant performance requirements concern local content and technology transfer.

Local Content Requirements

Domestic content issues arise during the examination and comment period of the approval process to set up a joint venture. Unlike export performance, local content requirements are not statutorily imposed on WOFEs or JVs but are pressed on investors informally. They are not a transparent statutory requirement but rather part of an internal guidance for achieving a certain level of local sourcing[6].

The MII is very concerned with the process of localizing production in telecom equipment manufacturing and makes funds available to promote this[7]. The case of Shanghai Bell, the Sino-Belgian joint venture producing SPC switches, illustrates the process by which foreign JVs are encouraged to increase their localization. The target for Shanghai Bell's localization was 20% of total components for the first few years of its existence, gradually increasing to 70 per cent by 1993. The JV's performance was regularly examined and linked to the renewal of its licenses to import certain components. The government also required Shanghai Bell to set up a Domestication Division within the company to deal with increasing the local production of components (Shen 1999).

In 1987, the State Planning Commission internally issued the following method to be used for measuring companies' achievement in import substitution (Shen 1999):

$$\frac{\text{Total cost of all components} - \text{Total cost of imported components}}{\text{Total cost of all components}} \times 100\%$$

The government's push for greater localization of manufacturing seems to have had some success judging by the committed investments of some of the large foreign equipment players. Motorola, in particular, even encouraged this trend as part of its strategy to regain market share – in 1999 it had a total of $1.2 billion worth of investments across a range of telecommunications and electronics fields (Pyramid Research 1999b).

[6] It is important to note that, unlike export performance requirements, local content requirements are on the "illustrative list" of investment measures noted in the WTO's Trade-Related Investment Measures (TRIMs) agreement as inconsistent with WTO policies (Rosen 1999). In line with its accession efforts, the Chinese government has been proposing to remove local content requirements (CEInet 2001b). However, it has been argued that local content policies can still be hidden behind policy regimes governing 'infant industries' and the they may be subject to lengthy phase-out schedules (Rosen 1999).

[7] Interviewee #18.

Technology Transfer

It is the stated goal of the Chinese authorities that the establishment of joint ventures should encourage the transfer and acquisition of technology from abroad. Government regulations[8] contain references to the need for investors to introduce technology in order to gain approval for their venture. However, similarly to local content requirements, no statute plainly mandates that foreign enterprises must transfer technology. The rules on foreign investment do require technology considerations for a firm to qualify simultaneously for WOFE status (or in some cases gain majority status in a JV and hence management control), *and* access to the China market. Therefore, technology transfer is statutorily required only for the firms wanting to gain both (Rosen 1999).

China's technology transfer policy is guided by what is known as "market share for advanced technology transfer". Thus a precondition for considering whether to allow a company to establish itself in China is that it will make technology transfer a priority. The advantage that the Chinese government has in the telecom equipment sector is that it is able to play off the various firms such as Ericsson, Motorola, Nokia etc. against each other when granting them licenses to do business in China (i.e. between who makes the larger technology transfer commitment). Furthermore, a company's track record in transferring technology is a very important factor for the government in considering whether to allow it to expand its existing operations or set up new ventures. For this reason, foreign firms undertake extensive government and public relations exercises to emphasize the extent of their commitments[9]. The MII itself is very active in overseeing the progress of localization and technology transfer to domestic industry, and has committed funds to support this process[10].

According to the U.S. Department of Commerce (1999), the MII and Chinese JV partners claim to be frustrated about the slow pace of technology transfer from their foreign partners (and that what is transferred is often low-tech). Thus China is likely to continue pressing foreign companies to speed up the process of technology transfer and impose tougher conditions on companies seeking to enter the telecom equipment market. These include higher levels of technology transfer, higher export ratios, and the establishment of R&D centers in China.

Localizing Research and Development

The MII has come to realize that technology transfer over the past decade has failed to allow domestic companies access to the 'core technologies' of foreign firms. Therefore, the central government is beginning to encourage foreign companies to set up R&D facilities in China[11]. Local governments have been taking the lead in encouraging the localization of foreign R&D, including this issue into policies promoting high-tech

[8] Catalogue for the Guidance of Foreign Invested Industries. Approved by the State Council on 29 December 1997, and promulgated by the State Planning Commission and the Ministry of Foreign Trade and Economic Cooperation on 31 December 1997.
[9] Interviewee #10.
[10] Interviewee #18.
[11] Interviewee #18.

growth in their regions (CEInet 2001a). For example, the Shanghai government has introduced regulations which state that foreign ventures whose spending on R&D in China has increased by over ten percent from the previous year are eligible for income tax cuts equal to fifty percent of the annual spending in their Chinese facility. Furthermore, foreign R&D centers will be exempt from paying tariffs on imports of the necessary equipment (AI Consulting 2001a).

Trade-Related Policies Promoting Import Substitution

As of January 1, 1999, the MII introduced a new equipment licensing requirement: without either a Network Access License or a Network Access Identifier, equipment cannot be sold, advertised or used in China[12]. The MII's rationale for the policy is that former, looser licensing procedures were abused by foreign vendors. The MII is now able to control what equipment is imported, and how much. The main implication, however, is that local manufacturers have been given the opportunity to catch up with their foreign counterparts, as the licensing process favors locally-developed equipment (U.D. Dept. of Commerce 1999; Pyramid Research 1999a). In a report to the State Council, the MII has proposed using technology standards to support the growth of Chinese telecom equipment producers (U.S. Dept. of Commerce 1999).

The account made by Shen (1999) of the Chinese government's efforts to promote domestically manufactured SPC switching equipment is illustrative of the way in which it has vigorously pursued its policy of import substitution. The government instituted a range of related regulations and practical measures to compel companies to replace imported components with locally produced ones, namely:

- applying tariffs to the direct import of components;
- granting exemptions or low import tariffs to individual projects which were considered to be in the national interest, to ensure that the previous policy would not drive away advanced foreign technology transfer to China;
- urging companies which were using imported components to gradually reduce imports and replace them by locally produced ones in order to promote the spin-off of advanced foreign technologies; and
- in order to help realize import substitution, government financial support was available for promising projects[13].

[12] Licenses are valid for three years; a renewal application must be made three months before the license expires. The Telecommunications Administration of the MII has designated two Telecommunications Equipment License Processing Offices (TELPO) to process applications. It is to publish a catalogue of all license telecoms equipment, and operators will be barred from purchasing equipment not listed in the catalogue. Vendors are expected to report data on annual sales, quality control and post-sales service to the MII (Pyramid Research 1999a).

[13] The former Ministry of Machine Building and Electronics Industry (MMEI) and the State Foreign Trade and Economic Co-operation Committee were jointly in charge of controlling import licenses, granting low import tariffs, setting up targets for import substitution and examining their implementation by companies (Shen 1999).

In a move to curb imports of entire SPC switches, in 1995 the State Council cancelled the preferential policies of reduced duties and value added tax on imports of this type of equipment. Furthermore, since 1994 the National Planning Committee stopped approving SPC switch imports using foreign loans, except for special projects ratified by the State Council (Peng 1999).

5.4 POLICIES FOR IMPROVING DOMESTIC TECHNOLOGICAL CAPABILITIES ('SUPPLY SIDE')

The Chinese government has introduced numerous policies to build technological capabilities within telecom equipment manufacturers. Wu Jichuan, head of the MII, recently summed up some of the government's desired outcomes to these policies in a directive to manufacturers (Huan 1999). In this directive, he stated that equipment manufacturers should aspire to:

- Set up efficient management structures for operation and innovation.
- Closely follow technology trends.
- Focus on internal innovation and turn the fruit of such innovation into commercial applications.
- Raise the market share of domestically produced technologies.

A Historical Perspective: Reforming the National Science & Technology System

It is useful to first consider the wider efforts which the Chinese government has taken in the past to encourage technological innovation and commercialization within the information and communications industry. Under the centrally planned economy, the industrial research system was parallel to industrial production instead of being integrated into it, and was characterized as a "government-directed research system". During the post-1978 reforms, policy-makers sought to transform this into an "enterprise-directed research system", that is, reunifying the application of R&D to commercial goals.

In 1985, the *Decision of the Central Committee of the Communist Party of China on the Reform of Science and Technology Management System* was announced. Three major points of this decision were (Yu 1999):

1. Reforming the appropriation system. This meant broadening the sources of funding for R&D and encouraging investment by government departments and enterprises.
2. Developing a 'technology market'. This sought to promote the commercialization of technology results from research and to provide monetary compensation for them (rather than allocating them through administrative decisions).

3. Reorganizing the structure of China's S&T system so as to bring together research and education-oriented organizations with the enterprise sector, and thus encourage technology development and assimilation.

The effect that these reforms had in the telecom equipment sector was that the PTIC (which controlled the majority of the telecom equipment factories), and former MPT's R&D institutions, were allowed to become increasingly independent of the MPT. The MPT used to have jurisdiction over 31 R&D institutes. In the past, any technologies developed from these institutes were given freely to manufacturing firms. The reforms changed this relationship, because technologies were now perceived as profitable goods that were valuable in the market (Shen 1999).

Therefore, one of the main impacts that the reform of China's S&T system had on firms in the telecom equipment sector was to highlight the importance of building internal technological capabilities. They could no longer rely on technology being handed to them from the State, since the state had devolved control over industrial R&D management. Combined with the economic opening up of the country, companies turned to joint ventures with foreign firms as a method for technology acquisition (which the State tended to carefully orchestrate). Domestic manufacturers were also encouraged to gradually improve their own internal R&D processes.

National Science and Technology Development Programs

Out of the goal to make technological development more market-oriented came the 'Torch Program' in 1988. This program was sponsored by the State Science and Technology Commission and was aimed specifically at high and new technology enterprises, including the telecom equipment manufacturing industry. The Torch Program encouraged the spinning-off of R&D institutes from Ministries and other State bodies by consolidating their capital, human, and intellectual assets, and then setting them up as new high-tech businesses, or 'New Technology Enterprises' (NTEs), as they were called (Gu 1999). The ultimate goal was to foster the application of science and technology to commercial purposes and the building up China's high-tech enterprise sector, which was viewed as a priority by the State.

As a counter-balance to the commercialization of technology, the 'China 863 Plan' was established to foster high-quality fundamental research in China. The nature of this research was seen as more strategic and long-term. The 863 plan has seven areas of focus, including the development of "state-of-the-art" information technology and laser technology. The former includes telecommunications technologies, and the latter has important applications in the field of optical communications.

Promoting Home-Grown Intellectual Property

The Chinese government, and the MII in particular, is anxious to develop Chinese intellectual property. The pragmatic reason for this is that using foreign technology involves costly purchasing or licensing of intellectual property. For example, it is estimated that China has paid nearly US$ 10 billion to overseas corporations for obtaining and licensing technology related to first- and second-generation cellular systems over the past 10 years (AI Consulting 2000f).

The government is therefore heavily sponsoring Chinese intellectual property within various facets of telecom technology. Most notably, China has been granted by the International Telecommunications Union (ITU) the recognition of a Chinese standard for third-generation (3G) mobile communication called TD-SCDMA. Third-generation mobile communications is an area of technological expertise that the government wants to promote within China's domestic industry (Pyramid Research 1999b).

Also in the area of mobile communications, the Chinese government has initiated a 'technical cooperation State Project' to develop 2.5G GSM (GPRS) mobile phones[14]. Eastcom, China Huada Integrated Circuit Designing Center and Motorola (China) Electronics will jointly develop this product. The target of the project is to successfully develop 2.5G mobile phones with China's own intellectual property rights for large scale production. In order to achieve this, Eastcom has formed R&D agreements with China Huada and Motorola (China) Electronics (AI Consulting 2000d).

Performance Requirements and Incentives for Promoting Technological Innovation and Commercialization

Disciplining and Encouraging the Growth of High-Tech Enterprises

Chinese new and high technology enterprises are exempt from import duties and value-added tax in importing key technologies and equipment. All investment projects that conform to the *Catalogue of Industries, Products and Technologies That Are Encouraged by the State* are eligible for this treatment. Among these are several types of telecommunications technologies. Furthermore, Joint Ventures classified as high technology companies under the 1979 *Law on Joint Ventures Using Chinese and Foreign Investment*, JVs also qualify for tax holidays if they are "equipped with up-to-date technology by world standards" (Shen 1999).

In addition to these regulations, the government has also shaped the incentive and resource structures of enterprises by manipulating institutional structures of property rights. One means of doing this has been the establishment of special high technology and economic development zones (the Wuhan East Lake High Tech Development Zone discussed in *Chapter 4* is one example of many). Within these zones, the government has

[14] 2.5G is the generic name for intermediate standards to be used for graduating from first-generation to third-generation cellular communication.

adopted institutional devices nested in the taxation process and investment processes that redistribute resources to strategic sectors. In the taxation process, sophisticated tax concession schemes have been devised to promote innovations in products and processes for enterprises in targeted industries. In the investment process, the devices include setting aside special venture loans in state banks with interest rates no higher and sometimes lower than normal commercial loans for investment in innovative products, lower equity-to-debt ratio requirements for bank loans, etc.

What is unique about the redistributive devices just described is the regulatory regime imposed upon it. In granting telecom equipment companies special legal status as 'science & technology enterprises', the government obliges them to meet certain requirements (Lu 1997). These include the following:

- percentage of technology personnel employed;
- percentage of sales contributed by new products;
- percentage of products exported;
- allocation of retained earnings; etc.

These institutional devices and corresponding regulatory regimes have been designed to create incentive and resource structures to induce companies to pursue continuous improvements in products and processes. Therefore the support which the Chinese government provides to telecom equipment manufacturers (and S&T enterprises as a whole), is combined with mechanisms to discipline industry according to State goals.

Incentives Targeted to Developing Specific Technologies

In order to encourage the production of larger-capacity transmission technology, the Chinese government has implemented a policy that exempts local and foreign companies from taxes if they produce transmission equipment with a capacity higher than 2.5Gbps. This incentive has several implications: it promotes China Telecom's goal to have one of the most advanced telecoms infrastructure in the world (in terms of network scale, technology and quality of service by 2010); it is in line with an objective to have advanced equipment with 20-40Gbps SDH or higher speeds deployed on the optical trunk lines; and it encourages local companies to speed up the development and manufacture of larger-capacity equipment and compete with foreign suppliers (Pyramid Research 1999a).

Promotion of Domestic Corporate R&D

The MII has established a special fund, part of which goes to supporting industrial R&D in telecommunications equipment. The fund consists of about 3 billion RMB per year, 40% of which goes to supporting R&D within the mobile communications industry[15]. This part of the fund is mainly distributed to Huawei, Zhongxing, Julong, Datang and Jinpeng. The government is also intensively funding fiber optic R&D and trying to foster companies that can become suppliers of fiber-optic equipment (Richards 2000).

[15] Of the 3 billion RMB, approximately half is obtained from installation fees and the rest is subject to yearly budgetary approval by the SPC and SETC (Interviewee #18).

Promoting the 'Fundamental Industries'

The so-called 'fundamental industries' are those industries which underlie the information and communications technology (ICT) sector, and include the semiconductor and software industries. Policies promoting these industries are defined at the central level and applied by local governments.

The State Council's Tenth Five-Year Plan, beginning in 2001, incorporates several goals intended to encourage the development of software and integrated circuit technologies. In particular, it seeks to develop Chinese intellectual property in "core technologies" related to large-scale integrated circuits and large-scale systems software (AI Consulting 2001b). Furthermore, the State Council has also issued a regulation entitled *Policies for Encouraging the Development of Software and Integrated Circuit (IC) Industries* (AI Consulting 2001a).

Local governments have sought to materialize these goals. For example, the Beijing municipal government has released a series of preferential policies designed to encourage the development of the city's software and integrated circuit industries. These include the allocation of special funds, preferential land-use rights, and the loosening of restrictions on personnel management. Beijing plans to establish four high-tech industrial centers for software and microelectronics (AI Consulting 2001c). Similarly, the Shanghai government will allocate 500 million RMB ($US 60.48 million) into special software development funds, including the setting up of a science and technology venture capital fund. Furthermore, newly established chip production projects will be granted tax exemptions.

5.5 Other 'Micro-Level' Policies for Promoting Domestic High-Tech Enterprises

Human Resources Policies

Before the economic reform process took hold in China during the early eighties, human resources policies were governed by very rigid rules on remuneration, promotion, etc. For example, in the past all the chief officials regarded as important to a telecom-related firm such as the director, major department managers, chief engineer and accountant, etc. were appointed by the former MPT (Shen 1999).

Similarly, recruitment of graduates from telecom universities and institutes (most of which used to be run by the MPT) was orchestrated annually such that students were assigned to work in particular factories and companies (Shen 1999). Today, graduates with a good degree or from a reputable university can choose where they prefer to work (Shen 1999). The rules surrounding work permits, or *hukou*, that used to constrain individuals into working within certain geographical areas, have been considerably loosened so that the supply of talent may meet the demand. The reforms which have made science and technology industries more important have also increased demand for qualified university graduates.

Furthermore, political controls upon private and joint venture companies were loosened, so that many firms accepted new employees without official leaving certificates as long as they had professional qualifications. Skilled workers and qualified engineers could quit and leave their firm for better-paid jobs in a joint venture or private company (Shen 1999). This has considerably increased the free movement of labor (and often with it the knowledge acquired from work-experience).

Lastly, powers have been considerably delegated to companies with respect to how they organize and incentivize themselves internally. This first began with Chinese-foreign joint ventures and has been extended to domestic companies. Thus, Chinese firms are at liberty to determine material rewards such as performance-based salaries, the offering of stock options, etc. These have been used by companies to spur internal innovation and productivity and, in companies such as Huawei, have apparently been a success[16].

Establishing New Avenues for Obtaining Capital

Traditionally, the only means for enterprises to obtain capital was from state banks. Although these bodies still provide a lot of financing to telecom manufacturers (see above), the government has sought to open up new sources of capital that are oftentimes more appropriate for the risky nature of certain new high-tech ventures. The government is also keen to alleviate pressure on the banks as the sole source of funding (other than a company's own profits).

Thus, the central government has been building up China's equity markets over the past years, and has encouraged some of the state-owned telecom firms to list and sell shares as a means of obtaining financing for their operations. Companies that have so far listed on the Shenzhen or Shanghai stock exchanges include Zhongxing, Datang and EastCom (U.S. Dept. of Commerce 1999).

Venture capital will also be used to raise development funds needed by domestic telecom companies. For example, the MII has signed a memorandum of understanding with the U.S. company International Data Group (IDG) to set up a venture capital fund of $100 million over three years to support the growth of China's telecom industry.

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[16] Interviewee #6.

Industrial Policy

Promoting Big Business

In other sectors of the economy, the government aims to transform the bigger SOEs into world-class conglomerates, and will encourage mergers among leading firms in order to achieve this (Pyramid Research 1999b). It remains to be seen whether this policy will also be applied to the telecom manufacturers since, as a whole, domestic production tends to be relatively decentralized when state-owned holding companies such as Datang and firms under the jurisdiction of the PTIC (such as Julong) are taken into account. These feature numerous factories and R&D institutes under a loose (and often confusing) management structure which is partly seen as causing the recent loss of competitiveness of the Julong company[17]. As stated by an MII official, the government aims to establish only a few large telecom equipment companies that are able to compete against the dominant foreign firms. The government wants big companies, rather than allowing a proliferation of smaller firms for which it would not have the resources to support. Therefore, the policy is to promote a 'Top 10' or even 'Top 5' companies in the telecoms equipment industry, as is being done in other sectors[18].

Promoting Small and Medium Enterprises (SMEs)

The government is also putting in place policies to promote the SME sector with a view to encourage technological innovation. These policies, currently under consideration within the draft *SME Promotion Law*, include the following (CEInet 2001a):

- incentives for technological innovation;
- establishing an SMEs development bank;
- encouraging SMEs to finance themselves through IPOs;
- promoting venture capital (VC) investment in SMEs; and
- encouraging the mergers and acquisitions of SMEs.

Industrial Licensing of Domestic Producers

The central government decides which domestic manufacturers are granted licenses for the production of equipment. For example, the government initially granted licenses to a small number of companies to produce SPC switching equipment[19]. Similarly, the government has granted licenses to produce CDMA equipment only to certain companies[20].

The government issuing of licenses is primarily a mechanism to control the level of competition within the industry. This has been spurred by the detrimental effects that fierce price competition in switching equipment has had on the profitability of the

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[17] Interviewee #10.
[18] Interviewee #17.
[19] Interviewee #2.
[20] Interviewee #15.

industry[21]. In the view of certain government officials, industrial licensing will continue being used as a means to control the number of competitors within the telecom equipment industry[22]. In particular, once Chinese manufacturers, including JVs, are capable of meeting demand, the door for newcomers is oftentimes closed. One good example is the MII's November 1998 announcement prohibiting any new JVs from producing GSM equipment.

5.6 CREATING FAVORABLE DEMAND CONDITIONS FOR THE DOMESTIC INDUSTRY ('DEMAND SIDE')

Technologically Sophisticated Government Purchasing Policies and National Telecom Infrastructure Development

China Telecom procures the latest and greatest technology and continues to upgrade its network, largely because of the important position the telecoms sector holds in China's economic development plans. The former MPT – which created China Telecom – has proposed a strategy of "high starting point with leading technology". This encourages the introduction of the most advanced technologies into China, and is credited by the government for having propelled the technological level of the domestic industry to a much higher level than if the country had focused on older technologies (Huan 1999).

Under the government's goal to "informationalize" China (AI Consulting 2001b), the MII is encouraging several initiatives that will spur demand for the most sophisticated kinds of communications and information technologies. These include accelerating the construction of next generation broadband telecom networks by adopting DWDM optical technology[23], third-generation wireless communication and Internet Protocol-based communication.

Thus, in being a technologically sophisticated buyer and pushing for the incorporation of the most advanced technology within its networks, the Chinese government is creating the demand conditions for companies producing equipment at the higher end of the technology spectrum. This, of course, makes it more challenging for Chinese companies which have started from a low level of technology. However, in conjunction with the localization policies described above, it is still providing the market opportunities for domestic companies to pursue.

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[21] In the switching market, prices have been dropping on an annual basis. In 1997, Siemens BISC sold its CO switches at 40% of 1992 prices; in 1998, they sold for 32% of 1992 prices. Average switching prices hovered round $110-$115 per line in 1995. By 1998, vendors were selling switches for $40-$60 per line.
[22] Interviewee #17.
[23] China began large-scale DWDM implementation in 1998 after signing its first DWDM contract with Lucent Technologies in August 1997 to deploy the technology on its Xi'an to Wuhan network (Richards 2000).

Reform of the Telecom Services Sector

The reorganization and restructuring of government institutions described in *Section 5.2* above announced the beginning of a new phase in the development of China's telecommunications market. The former MPT – which is essentially at the core of the MII – built, managed and operated domestic long distance and international services through the Directorate General of Telecommunications (DGT). In an effort to separate the regulatory powers of the MPT from its parallel function as the country's telecom operator, the DGT was officially spun off as an independent body in 1994, and incorporated as China Telecom in 1995 (Pyramid Research 1999b). Subsequently, the monopoly-type powers exercised by China Telecom, and the fact that it still enjoyed the patronage of the MPT/MII, brought it under the sights of government reformers. Therefore, under a wide-ranging 'anti-monopoly plan', China Telecom is being separated into four operating companies: fixed-line telephony, mobile telephony, paging and satellite communications.

In the near future, it is expected that China Telecom will again be re-organized into six regional areas. This geographical reorganization is widely expected to be the first step on the path towards a regional divestiture of local or regional operating companies, possibly along the lines of the 1984 divestiture of the Regional Bell Operating Companies in the U.S.. The possibility of this happening has encouraged provincial telecommunications administrations (PTAs) to vie with each other to take the lead in their respective regions. A related aspect of this program would see a further separation of the transmission, data communications and public switched-network businesses (Pyramid Research 1999b).

In an effort to promote competition in the telecom services sector, in December 1993 the State Council authorized the introduction of competition by approving the establishment of China Unicom as a second wireless operator. In August 1993, the former MPT decided to allow domestic non-MPT institutions to operate in nine "non-basic" or "value-added" telecom services sectors including paging services, data communications, and value-added services (VAS). The latter include domestic VSAT communications, telephone information services, computer information services, electronic mail, electronic data interchange (EDI) and videotext. In 1999, the government gave approval to China Telecom, China Unicom and Jitong Corp. to enter the internet telephony services sector (Pyramid Research 1999b).

Thus, the past few years have seen the government approval and licensing of three new national companies which did not originate from the MPT. These are China Unicom, China Netcom, and Jitong Corp. As a consequence of reforms in the services sector, there are currently six basic telecom companies operating in China[24] (AI Consulting 2000c):

[24] A seventh company, China Railcom, has received a telecom license. However there are suggestions that it may merge with China Unicom.

- *China Telecom* – operating fixed line telephone, international telephone and data services. Likely to receive a mobile phone license (possibly CDMA).
- *China Unicom* – second largest wireless communication company in China.
- *China Mobile* – mobile phone operator (spun off from China Telecom)
- *China Satellite Group* (spun off from China Telecom)
- *Jitong Corp.* – Internet access
- *China Netcom* – broadband networks

The central government is going ahead with plans to foster greater competition in the country's telecommunications services sector – albeit under its own terms (CEInet 2000). Upon joining the WTO, China will gradually open up to foreign competition in the 'basic' telecom services sector. According to its telecommunications agreement with the European Union (which will be applied to all other WTO members) the process will begin by allowing foreign companies to own 25 percent of domestic telecom ventures upon China's accession to the WTO. This will be raised to 35 percent after one year, and 49 percent after three years. The market for 'value-added' telecom services will be opened up more quickly and foreign companies will ultimately be able to own up to 50 percent of a venture's equity.

It is important to note that a fundamental characteristic of China's telecom services market that differentiates it from most other countries is that it is essentially policy-driven rather than market-driven (Sun 1999). Indeed, the government is strengthening its role in guiding the telecom industry. One important implication of this for the domestic equipment manufacturing industry is that the central government can control the issuing of licenses for telecom services for the benefit of Chinese industry. It is widely acknowledged that domestic companies 'missed the boat' with respect to mobile GSM communications – leading to the overwhelming domination by foreign equipment firms such as Nokia and Ericsson[25]. In the future, the government will therefore seek to ensure that domestic manufacturers have an established capability to produce equipment related to a particular telecom standard before services using this standard are allowed. In effect, the Chinese government is able to control the *timing* of the opening up of entire equipment markets (hence the description of this sector being policy- rather than market-driven). An example of this has been the recent postponing of Unicom's CDMA license, while local manufacturers such as ZTE are establishing their capabilities in CDMA systems manufacturing and implementation. It is predicted that the government will practice this policy when deciding to implement third-generation mobile communication standards (Chinese firms are currently trying to develop their own lines of 3G products).

[25] Interviewee #21.

6 Product Development Strategies and Processes

6.1 INTRODUCTION

This chapter examines the experience of Huawei Technologies and ZTE Corp., widely considered to be the top two Chinese telecom infrastructure equipment vendors. Information for these case studies was gathered from interviews with managers and engineers working at the companies' facilities in Beijing and Shanghai, as well as from information found within industry news databases[1].

The case studies deal with two principal aspects of technology strategy:
- Firm research & development capabilities and processes
- Technology supplier relationships

The first of these – firm research & development processes – discusses the most significant aspects of R&D processes and strategies within the firms in question, including organizational and cultural issues. It is important to understand the product development processes of these companies as these provide an indication of their technological capabilities. This was achieved by looking at how Huawei and ZTE go about developing certain products that are considered to be technologically at the high end of telecommunications equipment.

Secondly, supplier relationships with global technology vendors are an important factor in the product development strategies of Chinese telecom equipment companies. The case studies highlight two types of suppliers: 'platform technology' suppliers, and product suppliers. The first type of supplier provides a 'platform' (either hardware or software) to the buyer who uses this ready-made technological framework to develop new products or systems based upon it. The platform typically integrates certain tools to develop new hardware or software, and the supplier often provides technical support to help the buyer implement these successfully. Product suppliers provide discrete pieces of equipment which the Chinese company purchases and integrates into the systems it offers to its customers.

[1] Lexis-Nexis Academic Universe database.

6.2 *Case Study 1: Huawei Technologies*[1]

R&D Capabilities and Processes

The importance Huawei attaches to research and development can clearly be seen from the numbers. Huawei employs over 6,000 researchers (40% of staff) spread among five R&D centers in Beijing, Shanghai, Nanjing, Hangzhou, Xi'an and Chengdu. Furthermore, 85% of its employees hold a bachelor's degree or higher, and 60% hold a master's or PhD (Huawei 2000b). Most notably, Huawei claims to plow back 10% of annual revenues into R&D. Given sales of US$ 2.654 billion in 2000, this could potentially translate into a very high investment in R&D. Huawei also has an office in Silicon Valley that helps the company keep abreast of the latest market and technology trends, thus also playing an important role in the R&D process.[2]

Huawei's R&D structure includes a special department devoted to developing what it calls "cutting-edge technologies" such as optical switching equipment. The research outcomes from this department are subsequently passed on to the company's other R&D centers for further development into commercial products.

According to a senior R&D manager at the company's Beijing research center, Huawei does not view R&D cooperation with foreign companies as an effective mechanism to gain technological competitiveness. The reason being that there is no reason for foreign firms to transfer their most advanced core technologies to a Chinese partner over whom they do not have management control[3]. It was stressed that, in order to become technologically competitive, Huawei needs to carry out its own R&D. Furthermore, if Huawei were ever to cooperate on research initiatives, it would only do so with companies that could offer the latest technology The company is not interested in older technologies or those which do not promise to generate much profit.

R&D cooperation between Huawei and Chinese universities is confined to the areas of more basic research, the results of which are fed into the company's own R&D apparatus. One of the main reasons behind research relationships with universities, it was said, was that these functioned as valuable avenues for recruiting talent[4].

An important aspect of Huawei's R&D efforts is the company culture and management processes it has set in place. This was emphasized by company researchers as one of the keys to Huawei's success in developing its technological capabilties. Engineers have a strong emotional motivation for Huawei to be the best, and demonstrate this through hard work. For example, each researcher has his or her own bedroll in their office, given that they put in long hours and often stay overnight. One chief engineer claimed to have only

[1] Background information on Huawei can be found in *Chapter 4*.
[2] The Silicon Valley office also acts as a liaison between Huawei and its ASIC chip suppliers in the US.
[3] Personal view of a Huawei manager, confirmed in interviews with managers from foreign companies.
[4] It is a known fact that Huawei places a lot of emphasis on aggressively recruiting students from top universities, more so than other companies.

slept an average of five hours per night during the two years it took to develop a new product for Huawei. Nevertheless, he described the pride he felt in contributing to the company when the product became a commercial success.

In addition to the personal drive of Huawei's researchers, there also exists a tradition of knowledge-sharing and cooperative problem-solving within the company. As one engineer explained:

> *"Researchers are encouraged to share knowledge rather than keep it to themselves. This accelerates learning and the rapid acquisition of technical experience by staff and new recruits. After two to three months, a fresh graduate recruit should have become an expert in some area".*

Lastly, the company also encourages its researchers with financial rewards. Huawei's policy is to "never disappoint in terms of salary" (no figures were provided, however it was understood that salaries are competitive with respect to those found in foreign JVs in order to attract talent).

Joint Research Relationships

In addition to its corporate R&D facilities, Huawei is undertaking joint R&D initiatives with certain foreign companies on specific topics. *Table 6.1* summarizes the nature of these relationships.

Table 6.1 Huawei Joint R&D Facilities

Partner	Purpose
IBM	As part of an agreement whereby IBM will supply Huawei with key components, the two companies have launched a collaborative R&D effort to make their respective products and technologies work more closely together, allowing customers to incorporate both in their products.
Intel	Huawei and Intel have signed a memorandum of understanding in order to establish a joint laboratory within Huawei's Shenzhen headquarters. The laboratory will develop components based on Intel's 'Internet Exchange Architecture'.
Lucent Technologies	Huawei and Lucent announced in 2000 the establishment of a joint lab to focus on microelectronics and optoelectronics. According to Huawei, the two parties will enter into closer technical cooperation based on the incorporation of Lucent's advanced components into Huawei's products. The joint lab will also serve as a platform for both companies to exchange technologies via a variety of technical seminars and conferences. The joint lab will also work with Lucent's Bell Labs which has facilities in Beijing and Shanghai.
Texas Instruments	Huawei and Texas Instruments have established a joint laboratory within Huawei's facility in Shenzhen to develop digital signal processors (DSPs) for its equipment.

Development of Internet Router Equipment

Huawei develops products in the fields of switching, optical, mobile and data communications equipment. The following is an account of how the company produced its first Internet router, a product that falls within the category of data communications. Routers are a relatively new (and commercially lucrative) technology for Huawei.

History of the Router Development Process

Huawei has been developing data communication equipment since 1995. The decision to develop routers was initially made when the company assessed that a large market existed within China for this type of equipment. An R&D center devoted to router development was therefore set up in Beijing to understand and produce this equipment. Huawei took two years to develop its first product, a "2501"-type router which is the most common type in use (similar to Cisco's 2501 model). In 1999, the company spent roughly RMB 1 billion (US$ 121 million) on developing data communications equipment, followed by RMB 1.5 billion in 2000 (US$ 181 million).

Today, Huawei's development efforts in the data communications field center around three research institutes: the Beijing Research Institute, the Shenzhen Research Institute, and the India Research Institute. The three institutes have a combined research staff of 800, 600 of which work in the Beijing Institute. In April 1999, Huawei set up a 30,000 square meter site in Beijing. Within this site is located the Data Communications Center, which includes the R&D Institute mentioned above as well as a Marketing Department, a Technical Support Center, a Product Testing Department, and a Training Center.

The development process of Huawei's first router involved three main problems: hardware architecture, software architecture, and microchip design. To tackle the first issue, engineers disassembled a foreign competitor's router to understand the inner workings and design of the hardware (such as the physical interfaces between the various components). Researchers then turned their attention to the product's software, which is actually the most important part of the router since it controls the running of the hardware. At the time, they faced two choices: either to purchase the software or to develop it themselves. Although the latter would take considerably more time, they nevertheless decided to produce the software themselves and obtained the expertise to do this from Huawei's software research institute located in India[1].

The last elements needed to produce the router were the microchips and related circuitry. Huawei did not have the expertise to produce these key components and therefore purchased them from Motorola. The purchasing agreement with Motorola included the transfer of knowledge for developing the required components based on Motorola's microchip platform. This consisted of design toolkits, technical manuals and software. In addition, Motorola provided technical assistance in the form of an engineer to help

[1] Huawei software engineers in the company's India center learned programming and quality management skills from Indian companies such as InfoSys. These were instrumental in producing the software required, not only for routers but also for the company's other products as well.

solve any problems. Therefore, based on reverse engineering of the hardware, proprietary development of the software, and purchasing of microchip components from a foreign supplier (along with the platform for designing the other necessary circuitry involved), Huawei was able to develop its own Internet router.

Huawei describes its routers as having a modular design as well as using a high performance processor and high speed bus technology. The router equipment uses the company's proprietary 'VRP system' software that supports fast routing, Quality of Service, and other features. This is the software that Huawei designed itself. Lastly, as part of the manufacturing process, Huawei's routers and other data communications equipment pass stringent quality control tests from production through to shipment. All of the company's production processes are certified to ISO9001 standards[1].

Results

Huawei claims to manufacture (as well as to have designed) all of its routers, including its high-end core/backbone routers[2]. Thus Huawei is able to offer a "total router solution" including the 1600 series, 2500 series, 2600 series, 3600 low/mid-end router series, NE08/NE16 high-end routers, and the NE50/NE80 high speed core routers. These are summarized in *Table 6.2*.

Table 6.2 Huawei Router Product Series

Model Name	Router Type
Quidway NetEngine NE80[3]	Core Router
Quidway NetEngine NE50	Core Router
Quidway NetEngine NE16	Backbone Router
Quidway NetEngine NE08	Backbone Router
Quidway R3680	Modular Router
Quidway R3640	Modular Router
Quidway R2631	Modular Router
Quidway R2630	Modular Router
Quidway R2601	Branch Router
Quidway R2606	Branch Router
Quidway R2608/09	Branch Router
Quidway R4001	Branch Router
Quidway R2501	Branch Router
Quidway R2509/2511	Branch Router
Quidway R1602	SOHO Router
Quidway R1603/1604	SOHO Router

Source: Huawei

[1] Information obtained from Huawei's website.
[2] Interviewee #6.
[3] The NE80 is due to be commercialized in May 2001. It has a performance of 80G backplane, 72 Mpps. (Interviewee #6).

Huawei continues to purchase certain key chips from foreign suppliers. For its high end routers, the company purchases high-speed network processors from IBM as part of their cooperation agreement[1]. This chip is one of IBM's newest products and enables the routers to process IP cell packets at speeds of 2.5Gbps.

Huawei's series of high-end routers were launched in August and October 2000. These have since been purchased by Beijing Telecom and Henan Telecom. With respect to its modular and low-end routers – the 1600, 2500, 2600 and 3600 series – these have been purchased by financial institutions and government departments[2]. Huawei claims that a report from the International Data Corporation (IDC) attributes a 13% market share to the company within China for its routers (although it wasn't clear whether this related to its low/mid-end routers, or its high-end routers)[3].

In 1999, Huawei sold a total of 33,000 router sets[4], superceding its sale of 6,000 router sets the previous year. Together with its other data communications products, router sales contributed to total revenues of US$ 275 million for the year 2000. This was six times higher than the US$ 47 million made on such products in 1999 (Huawei press release).

The routers developed by Huawei are part of its Quidway and Radium series of networking equipment which include Internet access servers, IP gateways, and ATM switches. According to the company, these enable it to provide a complete line of Internet products.

Technology Supplier Relationships

According to a company manager, one of factors that decide whether Huawei produces or buys a piece of equipment is the profitability of the product. With respect to the above example, routers are seen to be very profitable products and demand for them is growing within China. On the other hand, another product that is necessary for data communications networks are LAN switches. However, according to a Huawei manager, these no longer have high margins and are correspondingly cheap to purchase[5]. For these reasons Huawei currently prefers to buy them rather than make them.

The examples below demonstrate other reasons for Huawei to purchase technology from foreign suppliers. This technology comes in the shape of microelectronic components, other components, or entire pieces of equipment. Additionally, Huawei purchases so-called 'platforms' (either hardware and/or software) that provide a system of compatible

[1] Interviewee #6.
[2] The People's Bank of China has placed an order for over 100 Quidway R3600 series routers. In a recent signing of Phase II of its intranet project, the bank has selected Huawei's mid-end routers to be used for its core backbone network linking its head office with 9 regional branches. The sale is said to be worth RMB 1.1 million (Huawei press release).
[3] It has not been possible to independently verify the IDC figure quoted.
[4] A breakdown by router type was not available
[5] Interviewee #6.

standards, as well as a design environment, with which the company can tailor the microelectronics or software that run its products. Hence the suppliers of these platforms often also supply certain key components that act as the building blocks for further development (and on which they make a profit).

Platform Supplier Relationships

IBM Microelectronics

In 2000, IBM signed an agreement to supply components to Huawei and provide the company access to its R&D facilities[1]. IBM will supply network-processors (based on its PowerNP processor) and packet-routing switch technology as well as ASIC parts to Huawei, who will use these to build its 'next-generation' products. These types of components are used within routers and SDH equipment. The purchasing agreement is part of a collaborative R&D effort to make the respective products of IBM and Huawei work more closely together, thus allowing customers to incorporate both of their products. In order to do this, IBM will work with Huawei to develop and manufacture the high-performance ASICs the latter requires for its networking equipment.

A typical piece of communications equipment like a network router utilizes a variety of chips to efficiently manage and move data[2], and in most cases equipment vendors must rely on multiple suppliers for these chips. However, under this agreement, Huawei is able to tap IBM's broad suite of networking technology for the building blocks of its future networking systems. Huawei benefits from this as it does not have to invest money and manpower in developing a new platform and, in addition it also has access to IBM's intellectual property and expertise. Furthermore, using IBM's platform to make their products compatible is advantageous from a marketing perspective.

> *"Collaborating with IBM will enable Huawei to have faster access to the advanced networking technologies we need to quickly deliver high-end telecommunications equipment to our customers across the world. Our joint R&D activities are expected to further ensure that we can offer our customers fully-optimized networking systems."*[3]

IBM competed with several leading chip suppliers such as Intel for the contract with Huawei.

Motorola Computer Group

In 2000, Huawei decided to adopt Motorola's *Smart Network Platform* – including a highly programmable microprocessor – as a substitute to the ASICs it has traditionally developed for its equipment. This decision was made because of the rapidly changing data communications and 'smart network' technologies which necessitate constant re-

[1] Business Wire (2000b)
[2] These high-performance parts commonly include network processors, switching chips, ASICs and control point processors.
[3] Ojo (2000).

designing of the integrated circuits they use. Motorola's programmable processor enables Huawei to shorten its design cycles and therefore time-to-market for its products.

Motorola's *Smart Network Platform* includes a family of processors used in various pieces of networking equipment which makes them compatible with one another. Huawei decided to use this platform because of the increasing need for integration between these various products – hence the logic of purchasing them from a single supplier to ensure maximum compatibility.

> *"Motorola's Smart Network Platform is pulling those separate products together and providing the common application interface and tool set that will enable us to leverage our development in one product area across multiple product families."* [1]

This supplier relationship is consistent with Huawei's shift away from controlling its own core technologies to cooperating instead with foreign partners on intellectual property agreements that allow the company to shorten its design cycles[2]. This new approach to cooperation is being implemented by Huawei's ASIC design team, which it has developed into one of the largest and most successful in China.

Texas Instruments

Huawei signed a memorandum of understanding in 1997 with Texas Instruments (TI) for the latter to establish a digital signal process solutions (DSPS) joint-laboratory within Huawei's facility in Shenzhen[3]. The agreement allowed Huawei to develop world class communications products such as PBX switching equipment, wireless local loop systems and base stations using Texas Instruments' technology. TI equipped the lab with advanced development tools and provided technical support to Huawei who used it to train its engineers in the latest DSPS technology. The relationship between Huawei and TI is still ongoing, and in 2000 the company decided to adopt TI's digital signal processors for its asymmetric digital subscriber line (ADSL) infrastructure equipment[4].

VocalTech Communications Ltd.

VocalTech Communications is a leading supplier of Internet telephony solutions – also known as 'Voice over Internet Protocol' (or VoIP)[5] – and is credited with launching this industry in 1995. Since then, VocalTech has built one of the largest R&D teams dedicated to Internet telephony and played a leading role in developing standards. VocalTec technology is the current platform for more then 500 E1 lines[6] in the China telecommunications market.

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[1] Liu (2000b).
[2] Liu (2000b).
[3] PR Newswire (1997).
[4] Liu (2000b).
[5] This is the ability to run a telephone service over the Internet using Internet Protocol (IP) standards.
[6] 'E1' denotes a telecommunications channel of a certain capacity. There are 30 telephone channels per E1 line.

In 1999, VocalTech and Huawei announced a joint development, marketing and sales agreement to deliver Internet telephony solutions to Internet service providers and telecom carriers throughout China, Hong Kong and Taiwan. The agreement between the two companies focused on interoperability – allowing products from both companies to be mixed together to create hybrid end-to-end VoIP systems[1]. In the first contract of this relationship, Huawei purchased from VocalTech the *Ensemble Architecture* platform and all its components, as well as development and training services. In particular, Huawei's switching equipment will exclusively use VocalTech's award-winning *Gatekeeper* which acts as a key control point within a voice network.

Intel Corporation

Intel has signed a Memorandum of Understanding (MoU)with Huawei in relation with the development of the Intel Internet Exchange (IX) Architecture in China[2]. The MoU provides for the setting up of a joint-development laboratory within Huawei's Shenzhen headquarters.

The IX Architecture is Intel's new approach for designing networking and telecommunications equipment based on re-programmable silicon and open interfaces. IX Architecture provides a new level of integration, performance and programmability to OEMs such as Huawei that are developing network systems. OEMs can use IX Architecture to design systems without encountering the costs, risks and time penalties typically associated with ASIC design efforts. It is claimed that IX Architecture-based systems can be deployed more quickly and upgraded more easily (due to their re-programmability), thus speeding up time to market. Intel is also introducing a developer's toolkit to help facilitate product design and enable equipment suppliers to provide after-sales product enhancements to their customers.

Huawei has also joined the Internet Exchange Developers' Forum. This Forum is focused on making it easier for third-party developers to create flexible network solutions based on the IX Architecture. Benefits include in-depth training for building networks based on Intel's system, as well as early access to roadmaps and specifications.

Product Supplier Relationships

IBM

As part of IBM's agreement to sell components to Huawei and provide R&D support based on its network chip platform (see above), the American company has also signed an agreement to supply Huawei with 'next-generation' Internet routers and SDH optical transmission equipment[3]. As opposed to key components such as microchips, these are entire pieces of equipment that Huawei would integrate into its own systems. Using IBM's *PowerNP* platform to make their products compatible therefore allows Huawei to

[1] Business Wire (1999 and 2000c).
[2] Liu (2000a).
[3] ChinaOnline (2000).

easily incorporate its partner's equipment and offer it to customers as part of an entire package. This is very advantageous to Huawei as it can extend its product offering beyond its own technological capabilities to offer high-end communications systems.

SDL Inc.[1]

Huawei signed a supply agreement in 2000 with SDL Inc. (a San Jose, California-based high-tech company) to supply it with components for the DWDM systems it manufactures[2]. This demonstrates that once a Chinese company such as Huawei has understood the design and manufacturing process of a high-tech product like a DWDM, it can forge relationships with top class suppliers of key components as far afield as Silicon Valley.

Product Development, Manufacturing and Management Support

Huawei has also purchased consulting services and product management tools that it has used for improving its R&D processes. Although they are not directly incorporated into Huawei's products, they are included below since they contribute to building Huawei's technological competitiveness.

IBM

Engineers in Huawei's Beijing research center stated that the company had hired the consulting services of IBM advise on implementing a comprehensive R&D process across the company. In the past, IBM had also been hired to consult on employee compensation schemes, presumably linked to incentive structures to improve Huawei's R&D effectiveness.

Intersolv

A 1998 purchasing agreement between Huawei and Intersolv was reached so that Huawei could build an integrated applications development platform using *PVCS*, Intersolv's software configuration management solution[3]. *PVCS* is a management tool for product development across the enterprise, which Huawei decided to use to speed up its product-to-market cycle and improve competitiveness. Intersolv agreed to provide technical consultation, maintenance and product upgrades. As stated by a software engineer in Huawei's central research department, "the Intersolv *PVCS* product family offers strong capabilities in managing our software assets, thereby speeding up the development of information technology systems."

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[1] SDL has been acquired by JDS Uniphase, a major international supplier of optical components and subsystems (see *Chapter 3*).
[2] These components consist of 980-nm pump modules and arrayed-waveguide-grating (AWG) modules. These modules are key components used in both the long distance fiber optic networks and metropolitan DWDM systems. The agreement runs through 2001 and is expected to be worth over $20 million. PR Newswire (2000a).
[3] Newsbyte (1998).

PADS Software Inc.

In 2000, Huawei signed an agreement with PADS to purchase is *PADS-PowerPCB* layout system, along with other products. This system provides a powerful design environment for complex, high-speed printed circuit boards (PCB) manufacturing.

> *"Huawei represents the type of company that PADS is best equipped to serve - a high-end user of innovative design solutions with stringent customer requirements and tight time-to-market demands. With their dedication to high quality and efficient product development, Huawei required a high-powered, easy-to-use interconnect solution. Huawei selected PADS Software's products following a rigorous product evaluation, finding that our solution met all of their criteria."* [1]

Manufacturing and Other Management Capabilities

Although the emphasis of this case study has been placed on Huawei's R&D capabilities and technology acquisition activities, a word needs to be said about the manufacturing side of the company's operations. After all, it is the selling of products which brings revenues. Information provided by Huawei shows that 10% of the company's workforce (roughly 1,600) is involved in production. Large-scale production operations, located within is modern production center in Shenzhen, are managed through an Enterprise Resource Planning (ERP) information technology system. The production center itself is outfitted with "a range of leading-edge automatic production lines"[2].

Huawei has also established within its Shenzhen headquarters a 'pilot test' department, the function of which is described as 'optimizing' the product development process from R&D through to final production, so as to ensure the manufacturability of the products under development. This includes testing the quality of the materials used as well as the final product itself, such as the structural strength, pipeline smoothness, electromagnetic compatibility, aging, temperature resistance, and humidity resistance. The department also reviews the product design so that it is suitable for volume production.

With regards to improving its management capabilities, Huawei has benefited from consulting services from major international firms. IBM has provided services related to the installation of company information technology (IT) systems. The consulting firm Hay has also been employed to implement a human resources management system, and both KPMG and IBM have provided advice on financial management. Furthermore, Huawei has received support from the German National Research Institute of Technology with regards to implementing production and quality control processes[3].

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[1] Business Wire (2000a).
[2] Information obtained from Huawei website.
[3] Huawei (2000a).

Product Range and Commercial Success

The main part of this case study has focused on the development of Huawei's router equipment. In addition, the company has developed a range of products across various segments of communications technology (outlined in *Table 6.3*). This puts into perspective the company's track record in developing its own products, turning it from its origins in switching equipment into a technologically diversified company.

Table 6.3 Huawei Product Lines Being Marketed or Under Development [1]

Fixed Network Solutions	**Mobile Network Solutions**	**Data Communications Solutions**	**Optical Network Solutios**
Switching	GSM 900/1800	ATM	SDH
Optical Access Network	GPRS	GSR	DWDM
Fixed IN	Third-Generation (3G)	Routers (26XX, 36XX, NE08/16, NE50/80)	Metro
STP, BITS	Mobile IN	LAN Switch	OXC
Call Centers	Mobile Call Centers	Access Server	
ETS 450/1900 WLL	Short Message Center		

Source Huawei

Huawei has generally been the technology leader among Chinese producers across all of the above product categories. For example, in the field of optical transmission, Huawei was the first domestic company to commercialize a DWDM system in China[2]. Huawei's products also generally beat those of other domestic manufacturers in terms of transmission capabilities and features (for example in Internet router technology).

Huawei's technological lead relative to its domestic peers is translated into the company's higher revenue earnings. Huawei's sales revenues have been steadily increasing from US$ 1.08 billion in 1998, to US$ 1.5 billion in 1999, to US$ 2.65 billion in 2000. Sales are expected to reach US$ 5 billion in 2001[3].

[1] The company also has an ASIC (application-specific integrated circuit) design center which services its various products lines as needed.
[2] Information obtained from Huawei press release.
[3] Information obtained from Huawei web site.

6.3 *Case Study 2: Zhongxing Telecom Equipment (ZTE) Corporation*[1]

R&D Capabilities and Processes

ZTE carries out two types of R&D: one type involves keeping abreast of global trends in telecommunications technology, the other deals with actual research into the design and production of particular pieces of equipment. The first type of R&D is carried out within ZTE's 'Technology Center' which strives to stay informed of innovations and understand their importance to the company.

The second type of R&D has the aim of mastering the design and production of products for commercialization. This research focuses on products already on the market (e.g. supplied by foreign competitors) which the firm wishes to develop itself. ZTE's main R&D focus lies in optical transmission, data communication, and mobile communication technologies. These activities are carried out within eight R&D institutes, six located within China, and two located internationally.

Table 6.4 ZTE's Research Institutes

Location:	**Research Activities:**
Domestic R&D Institutes	
Beijing (est. 1998)	Integrated wave division multiplex (WDM); new generations of optical transmission systems (including passive optical network); data communication products.
Nanjing (est. 1993)	Large SPC switching systems; mobile switching systems; network management; intelligent networks; network products; ATM switching systems; access servers.
Shanghai I (est. 1994)	Fiber ISDN access networks; PCS access; ATM access switching; ISDN data terminals.
Shanghai II (est. 1998)	GSM900/1800 digital cellular mobile communication system; CDMA mobile communication system; mobile handsets.
Shenzhen	Third-generation CDMA mobile communications; SDH transmission series; wireless access; multimedia videoconferencing system; telecom power supplies; centralized monitoring, automation of transformer substations; and production testing equipment.
Xi'an (est. 2000)	Radio transmitter and receiver products.
International R&D Institutes	
Silicon Valley, USA	Collection and exchange of the latest technological developments.
Korea (ZTE FutureTel Institute)	CDMA mobile communication systems.

Source: ZTE

In addition to the institutes listed above, ZTE has invested in several joint-research initiatives with academic institutions and foreign corporate partners (see below). Some of these have emerged from the company's 'Post Doctor Station' set up in 1998, which

[1] See *Chapter 4* for a general introduction to ZTE.

has proposed eight research projects and established over twenty cooperative agreements with Chinese universities and science research institutes[1].

ZTE claims to invest over 10% of annuals sales into R&D. Out of a total staff of 9,000, 86% hold bachelor degrees or above, 2,000 employees hold master's degrees, and 300 hold PhD or post-doctorate degrees and diplomas. 40% of the company's staff is engaged in R&D (ZTE 2000). Specifically within the area of mobile systems, ZTE devotes about 1,800 of its people to R&D. The company is currently strongly focusing on 3G mobile systems (reportedly the most important R&D program at the company).

Seventy percent of ZTE's R&D effort is taken up in developing software, with the rest going into hardware development (on which the software is used). Accordingly, about seventy percent of ZTE's researchers are software engineers[2].

A company manager that was interviewed claimed that the company's R&D facilities are stronger than those run by the Ministry of Information Industries (MII). This was illustrated by the fact that the company's Nanjing research center has over one thousand researchers who are young (and thus trained in the latest technologies) as well as experienced. In contrast, the MII's institute in Beijing has less researchers, many of which are relatively old and inexperienced in the latest technologies. This may be a reason why ZTE was assigned to undertake part of the national telecom research projects of the government's "China 863 Plan" and the "China Torch Program" (see below), one of which is in the area of 3G mobile communications (ZTE 2000).

With respect to relationships between ZTE and government telecom institutes, cooperation seems to occur at the level of system design rather than product design. An example is the joint venture set up by ZTE in the Congo (the Sino-Congo Telecom Corporation) to implement a mobile phone system in the capital Kinshasa. At the time, ZTE itself did not have enough expertise to set up such a system (although it provided the equipment), and thus drew upon the knowledge of engineers from the MII's institutes to assist them in this task[3]. In addition, although ZTE seems to carry out most of its R&D independently, it does cooperate with university research institutes.

Lastly, the decision-making process at ZTE on whether or not to develop a product is performed at two levels. Firstly, a decision on whether to carry through or cancel a project is made by a committee within a particular company R&D institute. This committee subsequently reports back to a 'Technology Center' at the company headquarters which audits this decision[4]. The latter is in effect a coordinating mechanism to ensure a coherent technology development strategy occurs across the firm.

[1] Information obtained from ZTE's website.
[2] Interviewee #2.
[3] Interviewee #1.
[4] Interviewee #3.

ZTE's Participation in National Technology-Building Initiatives

ZTE has participated in, and received recognition for, various state-led technology development initiatives. As described in *Chapter 5*, this entails various forms of financial and technical support from government. In 1996, the company was chosen by the Ministry of Science and Technology (MST) as one of the high-tech enterprises to spearhead the 'Torch Program'. It was subsequently given an award by the MST in 1998 for its excellent performance record in the Torch Program during 1996 and 1997. Also in 1998, the company was designated by the State Economic and Trade Commission (SETC) as one of the national 'centers of technology development'. In 1999, ZTE took part in the national 'China 863 Plan' for the development of various communications technologies, including third-generation (3G) mobile communications, integrated access over optical fiber, and optical transmission systems. Again in 2000 ZTE was authorized to develop three particular technologies under the 863 Program: the baseband processing for 3G base station systems, the 3G core network, and 3G systems integration[1].

A ZTE manager who was interviewed stated that the company contributed the majority of funds to some of the national projects it was involved in, such as 'China 863'. Therefore, although theoretically the technologies developed from such State-initiated plans should be shared, in practice ZTE has been able to claim exclusive use for at least some of the results[2].

Joint Research Relationships

Similar to the case of Huawei, ZTE has established joint R&D efforts with academic institutions and other foreign telecom players. These are summarized in *Table 6.5.*

Development of Dense Wavelength Division Multiplexing (DWDM) Equipment

History of the DWDM Development Process

In 1998, ZTE established its Beijing R&D Institute to carry out research on Dense Wavelength Division Multiplexing (DWDM) equipment – a key product used in optical transmission networks. The decision was made to produce this equipment since it has proven to be very profitable for firms such as Nortel and Lucent in China. The first product developed by the institute was an 8 Channel/2.5 Gbps capacity DWDM. Since then, ZTE has rapidly improved the technical capabilities of their product such that they can currently produce an 80 Channel/10 Gbps DWDM[3]. Furthermore, the product development cycle by which ZTE has kept improving upon each previous model has significantly shortened since the inception of the institute as demonstrated in *Table 6.6.*

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[1] Information obtained from ZTE's website.
[2] Interviewee #3.
[3] Interviewee #4.

Table 6.5 ZTE Joint R&D Facilities

Partner	Purpose
Beijing University of Posts & Telecommunications (BUPT) *	On November 13, 1999, a joint lab was set up in Beijing with BUPT to perform research on optical communication systems, particularly in the development of OADM equipment. This is one of the major tasks of the government's '863' program (see *Chapter 5*). On August 15, 2000, a second joint lab was set up in Shenzhen with BUPT to carry out research on optical transmission systems.
University of Electronic Science & Technology of China (UEST) **	ZTE and UEST (a 'national key university') have set up a joint R&D center to focus on wireless communications, particularly in third-generation wireless technology.
Texas Instruments (TI)	ZTE and TI have established a joint laboratory within ZTE's Shanghai Institute II to focus on the development of the latest DSP (digital signal processing) technology. TI will provide a software design platform and technical support.
Motorola	ZTE has set up a joint lab with Motorola in Nanjing. The cooperation will be based in the fields of data and mobile communication. Phase I of the project is devoted to developing data communication products such as IP phone gateways and access servers.

* BUPT began R&D activities on high-speed digital optical fiber communication systems and DWDM systems at the end of the 1970s. Several key products have emerged from the university's research, such as coherent optical communication systems, 8x2.5Gb/s OTDM optical transmission systems, bi-directional DWDM systems, optical internet, key components of WDM optical fiber systems, systems architecture configurations, and ATM optical exchange technology.

** UEST is a national key university that trains engineers in the field of information technology and is involved in the national 'informatization' initiative.

Table 6.6 Evolution of DWDM Product Development at ZTE

Number of Channels	Capacity (Gigabits per second, Gbps)	
8	2.5	Initial product, took 1 year to develop.
16	2.5	
32	2.5	
32	10	
80	2.5	
80	10	Current product, took *3-4 months* to develop.

The first products were described as being imitations of competitors' designs and ZTE developed them by mostly purchasing components from suppliers. Gradually, the Institute acquired the capability to develop certain key components of the DWDM system such as the Air Duct Fiber Amplifier (ADFA) which it is now able to design. ZTE still purchases many of the components for DWDMs from both Chinese and foreign suppliers, and will continue to do so according the company's sourcing strategy and design capabilities. For example, the company still purchases certain components considered to be key, "high-tech" elements of the equipment.

Sources of Technical Knowledge

The Institute researchers identified four main sources of knowledge that helped ZTE refine its understanding of DWDM technology:

- Technical consultants from universities
- Government research institutes
- Sophisticated customer requirements
- Firm-specific, internally-generated knowledge

Technical Consultants

The company has reportedly often drawn upon consultants from universities for technical expertise in product design. Indeed, many professors in China's leading telecommunications universities (formerly under the jurisdiction of the Ministry of Posts and Telecommunications)[1] also work part-time as consultants to Chinese technology companies such as ZTE.

Government Research Institutes

Another source of technical knowledge has been obtained through cooperating with academic and State-run institutes on certain research topics. For example, within the context of the government-initiated and (partly) funded '863 program', ZTE cooperated with the Beijing University of Posts and Telecommunications, the Wuhan Research Institute, and Datang to produce Optical Add/Drop Multiplex (OADM) systems – another component within optical transmission systems. The scope of these cooperative relationships seems to have focused on applied research. The result of these relationships was a "semi-product" – one that is not yet ready for commercial development but on which further work needs to be done in order to bring it to market[2]. ZTE indicated that it had invested a lot a money into this program, for which it received two main benefits:

[1] Along with the ministerial re-organization resulting in the formation of the Ministry of Information Industry (see *Chapter 5*), the training institutes of the former Ministry if Post & Telecommunications (MPT) were converted into 'Telecommunications Universities'.
[2] Interviewee #4.

- The knowledge that it was developing a commercially viable product: the choice of technology developed was arrived at through various interactions between market players which agreed that this technology was particularly important for the development of the industry.
- The Chinese government provides a certain window of time during which the companies involved in joint development (such as ZTE) have the proprietary ownership of the technology. Thus the company can make a profit from its efforts by further developing and commercializing it.

Customer Requirements

Customers such as China Telecom and China Unicom provide the sophisticated demand and the required product specifications to Chinese equipment vendors. This market sophistication is partly generated by foreign vendors marketing their products to the government and to the domestic telecom carriers[1]. The latter then pass information gained about the latest technical specifications to Chinese companies. According to ZTE executives, these telecom operators put quality and technology above price in making purchasing decisions, thus applying pressure to Chinese manufacturers to produce the most up-to-date equipment if they want to capture market share.

Firm-Specific Knowledge

As one engineer put it: "the most important technical capabilities come from within the company itself". This type of knowledge comes from the experience of repeatedly designing products with ever more capabilities and thus travelling along the learning curve. The knowledge gained from designing and producing a previous DWDM model is applied to the next one, gradually reducing the product development cycle.

Lastly, a very important source of knowledge arises from the mobility of labor, as exemplified by the career path of one of the Institute's researchers. This engineer is currently a Project Manager responsible for the development of one of the DWDM subsystems, and has been with ZTE for a year. Prior to this he had worked at the Wuhan Research Institute (WRI) – a government-run organization under the MII which has a reputation as a leader within China in the area of optical multiplexing and DWDM systems. Within the industry, WRI researchers are prized for their knowledge and skills, and are wooed away by companies such as ZTE who offer high pay packages (including stock options) and the opportunity to lead their own research teams[2]. The basic research the WRI has undertaken over the past decade in areas of optical technology is thus diffused to other companies. This is achieved via the knowledge gained by its engineers who go on to develop commercial applications of the technologies on which they had previously developed an expertise.

[1] Nortel, for example, hosts special talks and study tours for top government decision makers and technical offers.

[2] Interviewee #4.

Results

ZTE has successfully commercialized its ZXWM-32 line of DWDM products (however sales figures were not available). *Table 6.7* summarizes some of the optical transmission products being sold by ZTE, including its DWDM system.

Table 6.7 ZTE Optical Transmission Systems

Model Name	Description
ZXWM-32	DWDM optical transmission system product series. This includes systems with transmission capacities of 10Gbps, 20Gbps, 40Gbps and 80Gbps.
ZXSM-150/600/2500	SDH optical transmission system product series. This can be combined with ZTE's DWDM products to produce transmission capacities of 10Gbps, 20Gbps, 40Gbps and 80Gbps.
ZXSM-150(V2)	Compact 155M SDH optical transmission system

Source: ZTE

Table 6.6 above provides more up-to-date information on ZTE's capabilities, specifically in DWDM optical systems. It shows that the highest capacity system that the company is currently able to sell reaches 800Gbps (80 channel x 10Gbps per channel). This is a very respectable capacity in comparison with what foreign companies currently offer, especially for a technology which is considered to still be relatively immature[1].

At the end of 2000, ZTE won a bid to provide DWDM transmission systems for the construction of China Telecom's optical Metropolitan Area Network (MAN) for the city of Wuhan. ZTE will provide its ZXWM-32 DWDM system for this project, which will enable a transmission capacity of up to 80Gbit/s while flexibly adding or dropping wavelengths.

Recent Changes in Product Development Strategy

Before 1999, ZTE's objective was to produce in-house all the technology that it sold and R&D programs were set accordingly. However in the past year the company's management has changed its product development strategy so as to concentrate on developing 'core technologies' on its own and purchasing the rest from suppliers. As explained by an R&D manager, the rationale for this new strategy is two-fold. Firstly, telecommunications technology changes too rapidly for ZTE to develop everything and stay technologically up-to-date. Secondly, customers want 'total solutions' which necessitate a complete range of products that the company does not have. Thus it makes sense to integrate the products offered by other suppliers in order to satisfy customers which demanded that a single vendor integrate and install all the necessary equipment.

[1] Hungjen Wang, MIT (personal communication). However, further investigation would need to be carried out to ascertain whether ZTE's equipment compares favorably with that of foreign companies in terms of quality and reliability.

Technology Supplier Relationships

The fact that ZTE is a sophisticated buyer of technology is summed up by the assertion made by a company executive that "Zhongxing only buys the most advanced technology from foreign firms". If needed, ZTE thus looks for suppliers of the latest technologies in order to meet the market's requirements as well as match competitors' offerings. Furthermore, before purchasing from a foreign supplier the company determines whether the equipment is compatible with its other products and whether or not it has the capabilities in-house to produce it.

It is apparent that ZTE has several partnerships with companies that supply it with platforms to develop certain applications, and in some cases also supplying it with the necessary components. These are summarized below.

Platform Suppliers

Texas Instruments

TI has established joint labs with ZTE to design digital signal processor (DSP) chips for use in ADSL access equipment. These labs include DSP development kits and technical assistance from the supplier. ZTE in turn purchases the components to be used from TI.[1] In addition, ZTE has also formed a joint venture with TI and two other Chinese mobile handset manufacturers to develop DSP chips for 2.5G handsets. Although this is in the field of consumer electronics rather than infrastructure equipment, it is an extension of the supplier relationship between ZTE and its US partner. TI has pledged to transfer its core DSP technologies to all its Chinese cell phone partners, and the alliance plans to field a GPRS chip set by the end of 2001.[2]

Motorola

ZTE has signed an agreement with Motorola to develop products based on its Smart Network Platform. The arrangement is similar to that between Motorola and Huawei, and includes the provision of development tools and assistance in using them.

Vertel Software

Vertel is a leading provider of mediation software[3] for telecommunications networks. It offers a variety of technologies and applications, supporting end-to-end network and service management with the highest quality of service for network operations.

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[1] Liu (2000b).

[2] This project is being funded and supervised by the Ministry of Information Industries (Liu 2000).

[3] This software enables a variety of devices such as mobile devices to become an integral, intelligent part of a company's network topology.

In 2000, Vertel sold the license to its telecommunications management network (TMN) product line to ZTE for implementation in several wireless projects[1]. ZTE will build network management applications that include the Vertel technology for two wireless service providers based on two different standards, GSM and CDMA. Thus the company was able to use a software platform developed by a third party to make its mobile systems technologically competitive, without expending effort on developing one itself.

Manufacturing Capabilities

ZTE has production facilities in Shenzhen, for switching equipment, and in Shanghai, for mobile equipment. The former are equipped with advanced manufacturing equipment and testing facilities, and cover an area of over 170,000 square meters. At present, annual production capacity is equivalent to 20 million lines of switching systems. The mobile equipment production facilities cover over 10,000 square meters, and monthly production capacity is currently at about 1,000 sets of carrier frequency for a single shift (ZTE 2000). In November of 2000, ZTE began the construction of new production facilities in Nanjing which will occupy an area of 77,000 square meters. These are due to be completed in 2001[2]. In addition to its facilities in China, in 1999 ZTE has established a manufacturing plant in Pakistan which went into operation in 2000. ZTE gained ISO 9001 certification in 1995, 1998 and 2000.

Product Range and Commercial Success

Similarly to Huawei, ZTE is a technologically diversified supplier of telecommunications equipment. The company's product range encompasses fixed networks, mobile networks, data communication/networking, and optical networks. ZTE's efforts in technology development across these areas have paid off commercially, as indicated below:

- ZTE's ZXWM-32, a DWDM optical transmission system, has been awarded network access licenses by the MII. These have been incorporated into the network in Beijing and Hunan.
- ZTE switching systems, access network and videoconferencing products have reached international standards in their level of technology. ZTE's switching and access products cover 20% of Chinese communication networks, and its videoconferencing system is incorporated into 60% of newly added capacity in China.
- ZTE was the first Chinese company to develop a viable CDMA mobile communication system.
- ZTE's series of ATM products have been widely used in China, including its backbone switch, access switch, access multiplexer, and service accessor.
- IP network platforms, such as the IP phone gateway, manufactured by ZTE have been successfully running on the public network. Its IP access server has been successfully

[1] Business Wire (2000d).
[2] Information obtained from the ZTE web site.

introduced within several provinces in China. Furthermore, its Voice-over-IP access gateway has been adopted by China Unicom in 93 cities within China.

From a technological standpoint, ZTE's success can be partly measured by its claim to over 300 patented technologies, ten of which were applied for through its participation in the government's "China 863 Program" and which are related to the area of third-generation mobile communications (ZTE 2000).

6.4 SUMMARY

Product Development Strategy and Capabilities

A common theme between Huawei and ZTE is the importance they place in building their R&D capabilities. They do not rely on establishing joint ventures with foreign partners to access technology and manufacture new equipment. Rather, they strive to imitate the competition through *their own internal efforts*. Importantly, their R&D efforts are directed at developing the capability to design products that are new to the company, as opposed to understanding how to manufacture products whose design is handed to them by foreign partners (as would occur within a JV).

Technology Supplier Strategies

The case studies above confirm the fact that Chinese companies can and do access world-class technologies through supplier relationships with foreign companies. Many of these have a strong 'platform' component to them, whereby the Chinese company adopts a technological framework developed by their supplier. This platform provides an environment for them to design systems specifically to their needs, and gives them immediate access to world-class technologies which in many cases their competitors equally utilize. Suppliers of the platforms also provide technical support to the Chinese partner, whom they consider to be a valuable long-term business partner[1].

The benefits derived by Chinese vendors in using such technology platforms can be summarized as follows:

- Rapid access to an advanced design and/or system operating environment, accompanied by technical support.
- A reinforcement of the 'configurational' nature of telecom technology (see *Chapter 2*). The adoption of a platform can improve the interoperability between the equipment developed by a Chinese company and that produced by foreign manufacturers (who either provided this platform, or use this same platform provided to them by a third party). This means that Chinese vendors may be able rely on the

[1] Leading technology suppliers often vigorously compete with each other to win supplier contracts with companies such as Huawei and ZTE (Business Wire 2000b).

ability to integrate higher end technologies into their product offering which they would not otherwise be able to do.

With respect to discrete product or component suppliers, the examples of Huawei and ZTE demonstrate that, if they are able to master the design of a high end product such as a DWDM, they can access the same suppliers of high tech components used to manufacture them as their foreign competitors probably do (such as the case of SDL Inc. supplying Huawei).

Sources of Knowledge

The above cases show that Chinese companies can access various sources of knowledge which they can use to develop their competitiveness in designing and producing high-end technologies. These are:

- Consulting – either on specific product design issues (e.g. hiring professors from telecom universities), or on broader R&D management (e.g. Huawei hiring IBM's consulting services).
- A mobile labor force that is highly educated and skilled.
- Technical support from suppliers
- Internal knowledge management systems
- Government-sponsored cooperation within the industry targeted at developing specific technologies (such as the 'China 863 Plan').

In addition, it has been stated that researchers from Chinese firms attend international conferences dealing with cutting-edge technology developments, and have the ability to absorb this knowledge and bring it back to their companies[1]. This is an important source of knowledge for companies such as Huawei and ZTE who have cultivated the capability to absorb and use this knowledge to design relatively advanced products and close the gap with the foreign competition.

[1] Interviewee #5.

7 Analysis and Discussion

7.1 *Introduction*

Chapters 3 through 5 discussed industry trends, both abroad and within China, as well as government policies relating to the sector. The previous chapter focused on the case studies of two domestic companies, Huawei and ZTE, examining their R&D and product development processes and strategies. This chapter will return to the core question Posed in *Chapter 1*. Namely, how can Chinese companies compete against foreign firms in the high-end technology segments of telecommunications equipment? Underlying this, are the deeper questions of what strategies the Chinese firms have employed to build their technological competitiveness, have these have been successful, and what has been the role of government in these matters?

In *Chapter 1*, the following three hypotheses were put forward to address this question:

H1 Heavy investment in internal R&D capabilities is increasingly becoming an important driving force behind the success of certain Chinese companies.

H2 Chinese firms are leveraging the 'configurational' nature of communications technology to avoid the need for costly investment of resources in building technologies from scratch.

H3 International supplier relationships established by Chinese companies have had an important impact on their technological, and hence commercial, competitiveness. The availability of, and ability to purchase, technologies from international sources has been an enabler for Chinese industry.

The following discussion will address these hypotheses in light of the previous chapters.

7.2 *The Role of Domestic Corporate R&D*

Characterizing the Corporate R&D of Domestic Companies

The first step in understanding the role of R&D carried out by domestic firms is to define it in more detail. A useful framework for this purpose is that of Amsden, Tschang and Goto (2001) discussed in *Chapter 2*, which proposes a taxonomy for R&D (see *Table 2.2*). The activities described by researchers from the companies' R&D centers most closely resemble *exploratory development* in terms of the framework's criteria with respect to research objectives, output, techniques and the qualifications and skills set of engineers.

It should be realized, however, that the R&D being undertaken probably contains a high degree of reverse engineering[1] - the main purpose being to imitate the most advanced products on the market, rather than develop entirely new products. In networking and optical communications, these two firms are close followers of the world technological frontier, embodied by market leaders such as Nortel, Cisco etc[2]. This is to be expected, since Chinese firms have only begun to actively develop these products in the last three to four years.

Nevertheless, as discussed in *Chapter 2,* the fact that R&D is applied to reverse engineering does not necessarily change some of its basic characteristics. The skills, methodologies, and problem-solving activities involved can approach that of 'original' R&D since, although a model may exist, much essential technology remains tacit and needs to be discovered through intensive internal effort. This is supported by the data on researchers' skills within these companies, a large proportion of their engineers having Master's and PhD degrees. For this reason, Amsden *et al.*'s framework can be applied to analyzing the domestic firms' R&D efforts. It should also be noted that *advanced development* is another part of the R&D activities undertaken by Chinese companies given that it is necessary for achieving efficient manufacturing of their products. A strong indication of this is provided by the case study of Huawei, which describes a 'pilot test' department within the company whose function is to optimize the manufacturability of the firm's products[3].

Responses given by R&D staff from the facilities of Huawei and ZTE indicate that certain elements of these companies' R&D programs may actually reach into activities akin to *applied research.* These correspond to research groups attempting to develop products that are not yet available on the market. One such example is the development of third-generation mobile communications technologies. The Chinese government has obtained certification from the International Telecommunications Union (ITU) for a new domestically developed standard for 3G mobile communications called TD-SCDMA. Although the technological roots of this standard lie in the current GSM and CDMA standards, it is still unique and different from the two other 3G standards being developed by the leading international equipment companies[4]. Chinese firms developing the hardware and software that will utilize this standard are therefore not imitating or superficially adapting products already on the market (3G systems are not yet commercially available[5]). Therefore there is nothing to reverse engineer or use as a model for development. It was not possible to tell from the available information how

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[1] Managers interviewed from the research centers maintain that their firms respect other companies' patents. Therefore there is a possibility that domestic firms are licensing certain technologies from foreign firms. This is unlikely, however, as it goes against the strategic interests of foreign companies given that equipment such as DWDM and routers lie in very profitable market segments and they have the option to export into the Chinese market or sell them through JVs (which better protect their intellectual property). Further investigations would need to be conducted to reconcile statements made by the domestic companies and the methods available to them for acquiring technology.

[2] As discussed in *Chapter 3*, the smaller technology companies that supply components and subsystems (see *Appendix 2b* for a selected listing of these) are also representative of the world technological frontier.

[3] See *Chapter 6*.

[4] W-CDMA and CDMA2000.

[5] Except in Japan, where a version of 3G, called iMode, has recently been implemented by NTT DoCoMo.

successful domestic firms have been in this type of research, however it does show that Chinese companies are beginning to tend towards more applied research as they develop their internal technological capabilities.

Software Development

Software is an essential aspect of communications equipment, and it is often complex and time-consuming to develop. The stability, quality and feature-richness of software are often key differentiating factors for a given hardware technology (especially when it is mature). Software development is an important aspect of product R&D, as illustrated by ZTE, where 70% of R&D at the company is focused on software, according to one manager. However, R&D related to software does not seem to fit into the framework of Amsden *et al.*, which is mostly geared towards physical goods. Nevertheless, in many cases software development still qualifies as 'research', and it requires the various processes of normal product development such as design, testing, de-bugging etc. Software is also usually developed from scratch (when it isn't licensed) as reverse-engineering can be near-impossible without access to the proprietary source codes of the program in question. Therefore, although a lot of R&D effort by the Chinese firms goes into software development, it is one area in which a different type of classification needs to be applied. One criterion may relate to the particular level of software complexity, such as functionality, interactions with hardware and other software, etc.

There are indications that the software skills of Chinese firms are considerable, since software programming applied to communications equipment and systems can be very complex. Links with the highly regarded Indian software industry seem to have been instrumental in some cases (such as for Huawei's development of Internet router software)[6].

Corporate R&D and Success in Product Development

The case studies of Huawei and ZTE show that these companies have developed advanced products as a result of their own investment in R&D. The know-how for manufacturing products such as DWDM systems, Internet routers and other pieces of equipment in their product portfolios have been acquired through heavy investment in knowledge-building, rather than as a product of technology transfer through joint ventures. This is a particularly salient feature of the four leading domestic firms, and especially of Huawei and ZTE. Neither of the two have extensively engaged in setting up JVs with foreign partners, thereby using them to break into a particular product market. Rather, their products have been self-developed.

The divergence between the 'go-it-alone' road and the JV/technology transfer road occurred at the beginnings of the industry in China[7]. Shen (1999) gives an account of two case studies in the development of SPC switches. One effort, backed by the Chinese

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[6] See *Chapter 6*.
[7] See *Chapter 4*.

government, resulted in the creation of Shanghai Bell (a JV between Alcatel and a domestic company). The other was an independent effort by a Chinese firm to develop its own version of the SPC switch, capitalizing on the fact that it could purchase many of the necessary components from abroad. Similarly, one can draw a mirror image between many other communications systems sold in China that have been either developed through joint ventures or self-developed by the four domestic leaders. An indication of this can be seen in the description of China's industry structure in *Chapter 4*. There is, however, a time lag, as in nearly all cases the technologies were initially introduced through joint ventures and later domestically developed. Nevertheless this time lag is shortening, as illustrated by *Figure 4.2*, presumably as a result of the improving absorptive capacities and technical capabilities of domestic firms.

From this perspective, the R&D efforts of Chinese firms have been a success. They have enabled these companies to reproduce a portfolio of products that meet market needs and oftentimes match those produced by foreign competitors.

A Comparison Between R&D in Domestic Companies vs Joint Ventures

In discussing the role of domestic corporate R&D, it is useful to contrast it with that found in Chinese-Foreign joint ventures. Amsden *et al* (2001) and Porter (1998) describe how the most important aspect of a firm's R&D is carried out within its home country. R&D performed by these companies in foreign countries where they have a direct investment (such as through a JV), is usually a case of *product adaptation* (falling under the 'advanced development' category. China very much conforms to this observation.

Because the products manufactured in Chinese-foreign JVs have, by definition, already been developed by the foreign partner, any R&D occurring in these companies usually relates to the adaptation of existing products for the Chinese market. This is often an issue of software development, as foreign-developed products need to be made compatible with Chinese communications standards and protocols. In an interview conducted at the Beijing International Switching System Corporation (BISC), a joint venture with Siemens[8], a manager described that the only 'R&D' the company conducts is in adapting software originally provided by Siemens.

[8] It is a direct competitor with Alcatel's Shanghai Bell JV, also focusing on the production of switching equipment.

Analysis of the Case Study Firms' R&D Processes and Strategies

The account given in *Chapter 6* of Huawei and ZTE's R&D capabilities and processes allows us to distill some key actions these firms have taken in order to acquire technology and build up their technological capabilities.

High Investment of Resources in R&D

Both Huawei and ZTE claim that they invest 10% of revenues into R&D. Furthermore, in addition to this level of expenditure, the case studies have shown that a substantial amount of human resources are devoted to R&D activities – approximately 40% for both Huawei and ZTE. Both companies also have numerous centers devoted to R&D on particular product lines.

Emphasis on Recruiting, Retaining and Motivating Talent

High quality R&D necessitates high quality human capital with the right skills. A professor at the Beijing University of Posts and Telecoms (BUPT) asserted in an interview that one of the biggest challenges for Chinese firms is finding the talent they require[9]. This is not surprising since it has been observed that, even in the U.S., there are talent shortages in areas such as optical communications[10]. Furthermore, even for the relatively small number of Chinese graduates with appropriate skills, domestic firms need to compete with prestigious foreign companies with a presence in China in order to attract them.

Nevertheless, firms such as Huawei seem to have been relatively successful in the war for talent. Huawei stands out by the manner in which it aggressively recruits the best and brightest from Chinese universities and research institutes by paying higher salaries than the standard for domestic firms. Huawei is also known to give very high salaries to the students of famous professors, to the extent that some industry observers define the company's HR strategy as a means of "storing" talent such that it is not made available to the competition[11]. Datang, another of the four leading domestic firms, has also been successful in obtaining highly qualified staff trained in the U.S., many of them graduates of MIT[12].

In many cases, the top domestic firms use their R&D relationships with top-tier Chinese universities to both promote themselves among students and identify promising researchers. Furthermore, a high proportion of recruits have Masters or PhD degrees, which is consistent with the fact that the highly technical nature of the work needs to be matched by an appropriate skill level[13]. Domestic firms cast their nets wide when

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[9] Interviewee #15.
[10] See *Chapter 3*.
[11] Interviewee #15.
[12] Interviewee #15.
[13] Even undergraduate recruits come with high skill levels since undergraduate education is specialized, rather than of a liberal arts nature, and many university programs emphasize a high degree of practical skill by working on research projects throughout a student's education. For instance, students from the Beijing

looking for skills as they also try to attract experienced researchers from well-respected institutions such as the Wuhan Research Institute (which is strong in optical technology).

In terms of retaining talent, Huawei is also a good example of how domestic firms have increasingly been using share options to both keep and motivate staff. However, Huawei in particular has been known to also lose staff because of its managerial culture, which some describe as "too American" – a reference to the pressures of the hard-driving work environment[14].

Use of External Sources of Knowledge

Both Huawei and ZTE have shown an ability to utilize knowledge from outside their firm in order to complement their own expertise. For example both companies have drawn upon the knowledge of professors from well-known technical universities acting as consultants. In this way, domestic companies are able to access the state-funded knowledge accumulated within the country's academic institutions.

Huawei has also called upon the consulting services of foreign companies. For example, IBM is advising it on implementing the process of 'integrated product development'. Although this is more 'managerial' rather than technical knowledge, it is a very important contribution to Huawei's internal R&D capabilities, enabling it to manage them in a better, more efficient manner. Two interviewees stated that understanding how to manage the R&D process is crucial to the success of domestic firms[15].

Researchers at ZTE have stated that international scientific forums and exchanges have been a useful source of new knowledge for their company. Their top researchers are proficient enough to understand the material presented and thus feed it back to their own organization's R&D processes[16]. This is a tribute to the training provided within certain academic institutions from which these researchers are recruited. Domestic firms also try to absorb technical knowledge abroad by placing 'listening posts' in centers of innovation such as Silicon Valley (both Huawei and ZTE have offices there). These centers are responsible for tracking trends and innovations in technology, and reporting them back to their company headquarters.

Lastly, domestic companies have formalized technological exchanges by entering into R&D cooperation with academic institutions as well as foreign companies. Cooperation with Chinese academic institutions often occurs within the context of a broader government program such as the 'China 863 Plan'. One example is the cooperation between ZTE, Datang, the Wuhan Research Institute, and the Beijing University of Posts & Telecommunications to develop an Optical Add/Drop Multiplexer (OADM), a key subsystem of a DWDM optical transmission system. This form of research could

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University of Posts & Telecommunications are highly prized because of the practical orientation of the program. (Interviewee #15).

[14] Interviewee #16. Ren Zhengfei, the ex-People's Liberation Army officer who founded Huawei, is said to have instituted a management culture not dissimilar to that found in the army.

[15] Interviewee #12.

[16] Interviewee #5.

probably best be characterized as exploratory development according to the framework proposed by Amsden *et al.* (2000). In this particular case, the result of the four-way cooperation was a "semi-product" for which further development needed to take place in order to commercialize it. The participating companies could at this stage bring the project in-house for further advanced development. A ZTE manager described that cooperation between his company and academic institutions dealt with more "basic" R&D than what was conducted within ZTE[17].

Joint R&D relationships with foreign companies ranges from narrow in scope, such as product adaptations of key components (the most common form), to broader joint venture-type cooperation on entire systems (relatively rare). The first type of cooperation is often tied to supplier relationships, examples being the joint R&D labs set up by Texas Instruments (for DSP chips) and Motorola (for ASIC chips), within both Huawei and ZTE's own facilities. This kind of R&D probably falls under the definition of advanced development. Importantly, it provides domestic companies with the capabilities to use suppliers' design platforms to adapt and design certain key components.

More extensive, joint venture R&D cooperation between domestic and foreign companies seems to be relatively rare. The only such relationship found is that between Datang and Siemens, whereby both companies are jointly developing products for the Chinese 3G mobile standard, TD-SCDMA. Industry observers believe that both companies will share the intellectual property developed from the relationship[18], however details of this joint venture were not available. A statement from a manager in Huawei's Beijing institute may serve to illustrate management's policy with respect to R&D cooperation: "If Huawei ever decides to cooperate in R&D, it will only do so with companies that can offer the latest technology. We are not interested in old technologies"[19]. This may indicate that domestic firms only justify the tradeoffs that come with R&D cooperation (e.g. proprietary versus shared intellectual property) if it enables them to acquire up-to-date or next-generation technologies that would otherwise take much longer to develop on their own.

A Structured Product Development Process

The process by which Huawei and ZTE develop their products can be conceptualized as shown below, using information gained from the case studies in *Chapter 6*.

Product Identification. Firstly, firms identify a particular product or technology they wish to develop by analyzing market opportunities[20]. For example, Huawei decided to develop routers because the market in China is growing strongly and they are very profitable pieces of equipment. On the other hand, Huawei decided not to product LAN

[17] Interviewee #4.
[18] Interviewee #22.
[19] Interviewee #6.
[20] However, good judgement may not have been always used in the initial scoping of products. For example, Huawei spent a lot of money in developing GSM systems without realizing that they would not be able to capture the share of China's market necessary to make this investment worthwhile. However, the company may yet be successful in developing country markets (Interviewee #16).

switches (purchasing them instead) due to the high competition and low margins of these products[21]. Furthermore, Chinese firms actively keep abreast of technological developments in the field and track demand trends for particular products. This is carried out via 'listening posts' they have established abroad within centers of innovation, such as Huawei and ZTE's research centers in Silicon Valley and New Jersey, U.S.A..

R&D Ramp-up. Once a potential product has been identified, a preliminary team of researchers is set to work on understanding the technology. If the equipment belongs to a particular line of products the company has already established, this activity generally takes place within the R&D centers dedicated to it. If R&D on the product is looking promising, the resources allocated to it are increased and a separate research center may be established to host the expanded staff (e.g. Huawei's Beijing Institute dedicated to routers, and ZTE's Beijing Institute dedicated to DWDM systems). ZTE's case illustrates a process by which the company makes the 'go/no go' decision on a project. An initial decision on whether or not to continue with a particular project is made by a committee within the relevant R&D institute. This committee subsequently reports to a 'Technology Center' at the company headquarters which audits the committee's recommendations and makes a final decision. In this manner, the company coordinates its product development processes across the firm while delegating a degree of responsibility to individual research teams[22].

Integration with Manufacturing. There are several indications that product development takes place with an eye to manufacturing. For example, Huawei has what it calls a 'pilot test' department whose function is to optimize the product development process from R&D through to the production stage in order to ensure the suitability of the product for high-volume production. It could not be determined exactly what this 'optimization' consisted of, but it presumably includes elements of 'design for manufacturability' (DFM) and test assembly of the product.

Cycles of Improvement. Once the first version of a commercial product is finalized, R&D teams continue producing equipment with higher capacity and more features. Researchers become more familiar with the technology and build upon what they learned on the first product. Frequently, researchers with experience in producing the first product become team leaders and supervisors on subsequent product upgrades[23]. The firm thus reinvests human capital gained from previous projects. The shortening of product development cycles experienced by ZTE when improving its DWDM systems – starting with one year and currently down to 3-4 months – serves as evidence that these firms are nurturing their technological capabilities.

[21] Interviewee #6.
[22] Interviewee #3.
[23] Interviewees #6 and #7.

A Changing Product Development Strategy

There are some strong indications that the leading domestic companies are beginning to change their R&D strategies. In the past, the goal of Huawei and ZTE was to develop in-house all the products that they sold, and their product development strategies were set accordingly. However, several issues have made them reconsider this approach. Firstly, there is an acknowledgement that technology in this sector changes too quickly for them to keep pace with developments in each piece of equipment they wish to sell. Secondly, there is a demand from their customers for 'total solutions' which encompass a range of products that they currently do not have the time or resources to develop.

These factors have made the two case study companies consider establishing several alliances with component and equipment suppliers. This model of technology acquisition is analyzed in more detail in *Sections 7.3* and *7.4* below. A manager from one of ZTE's research institutes described the company's new strategy as focusing on the development of "core technologies" (such as such as software platforms and systems engineering)[24]. However, the impression gained from certain interviews is that domestic companies seem to be struggling to define the scope of what their technological core competencies should be.

The Goals of Domestic Firms' R&D Efforts

Chinese firms (and the Chinese government) have expressed the desire that, ultimately, they wish to develop their own intellectual property (IP). This is mainly because there is a cost associated with not having proprietary technology. This amounted to at least $US 10 billion in royalties and license fees to foreign companies for the acquisition of first- and second-generation technology for mobile communications *only* (AI Consulting 2000f). In an environment in which IP laws are increasingly enforced[25], domestic firms find that their cost structures are being affected by obligations to either license technology or pay royalties. For example, Qualcomm has signed agreements to ensure that domestic companies developing CDMA equipment will pay royalties for the technology it originally developed.

On the other hand, joint ventures frequently secure access to the right to produce the foreign partner's technology in exchange for the latter taking a certain percentage of equity. This often corresponds to a controlling stake in the joint venture so that the foreign partner may keep control over its intellectual property. Thus on the one hand, companies such as Huawei and ZTE are at a disadvantage with respect to joint ventures given that they need to incur IP-related costs. On the other hand, their efforts to develop

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[24] Interviewee #3.

[25] Although China is known for its lax protection of IP rights, it is having to beef up its record in order to reap the benefits of WTO accession. Furthermore, communications technology has a higher profile than many other industries and thus IPR breaches are more obvious. Furthermore, if Chinese companies wish to export abroad, they may be blocked from doing so if they are found to have infringed IP laws.

their own intellectual property have enabled them to build up internal R&D capabilities that Chinese-foreign JVs do not possess.

Self-Development vs. Technology Transfer: the Pros and Cons

It can be argued that self-development, in contrast to technology transfer through *production-oriented* joint ventures[26] is, in the long run, the better vehicle for promoting a dynamic and competitive telecom equipment industry in China. Initially, it is obviously harder for domestic companies to develop a particular technology since they do not have a partner willing to provide them with blueprints and know-how, obliging them to spend time and resources to catch up. However, once this initial hurdle is overcome, they gain control over the pace and direction of their own technological development (the only barrier being their own technological capabilities). In this industry, joint ventures are often subordinate to the foreign partner's interests. They are not necessarily designed to compete internationally against the foreign partner's own products, and purchasing decisions regarding key parts and components may favor the foreign partner as it is often the supplier of these. BISC[27] provides a good example of this kind of arrangement.

Production-oriented joint ventures (the most common kind in China) are set up for the purpose of manufacturing a particular line of equipment. When the foreign partner wishes to manufacture in China a different range of products, it will often set up a JV with a separate factory or institute which has loose or no connections with its other domestic partners. Many such firms may be owned by the PTIC[28], as described in *Tables 4.2-4.6* (see also *Appendix 3*). However, they may be located in geographically disparate locations, thus minimizing opportunities for organizational learning. The account given by Shen (1999) of the switching industry also shows that the interests of enterprises owned by the PTIC are not necessarily aligned, and rivalry can break out between them. This indicates that the PTIC probably cannot function as an efficient coordinator of knowledge transfer among its own enterprises. Furthermore, the task of staff employed in JVs is not to *discover* technology, but rather to learn how to assemble it through instructions and coaching (i.e. technology transfer). Therefore, a production-oriented joint venture cannot become a *technological learning environment* in the same way that domestic manufacturing companies such as Huawei and ZTE have become (at least with respect to product technologies).

An anecdote based on an interview conducted at a major Chinese-foreign joint venture (call it 'MFJV') illustrates certain points of the above argument. Although MFJV is majority-owned by Chinese interests and has achieved 100% localization of manufacturing, it is still effectively controlled by the foreign management with respect to strategic decision-making. The Chinese management of MFJV has wanted to expand into new product areas as they witness demand building for them in China. However,

[26] As opposed to joint ventures for which R&D is a large component, such as the Datang-Siemens JV to develop TD-SCDMA equipment.
[27] Beijing International Switching Systems Corporation (a JV with Siemens).
[28] The PTIC is a state-owned holding company that owns and manages numerous telecom equipment facilities across the country.

they have been constrained in doing so by two factors. The first is that the company has not built up the necessary expertise and internal processes to launch into new products on their own, and thus relies on the foreign partner to provide them with new technology. The second factor is that the foreign company itself may have interests in these new product areas, and it is taking time to decide whether to launch them in China through MFJV or through different channels (e.g. setting up another JV). Because the Chinese management of MFJV considers the company to be 'theirs' (i.e. a Chinese firm), these constraints have often been frustrating for them as they look at opportunities passing them by.

The pros and cons of self-development versus technology transfer, with respect to technology acquisition, are summarized in *Tables 7.1* and *7.2*. The analysis is based on conversations with managers from domestic and joint venture companies.

Implications for Chinese Industry

In answer to the first hypothesis, it can be said that domestic firms are increasingly relying upon their own technological capabilities in order to remain competitive, rather than just competing on price. This has been driven by the increasing sophistication of the market, which has left them with little choice but to acquire new technologies, and become better at developing them. Government policies have also played a significant role in this matter, as discussed below.

According to the observations, the case study firms have chosen the path involving heavy investment in R&D in order to improve their product technologies. This involves at least exploratory development, certainly advanced development, and perhaps some elements of basic research. On the other hand, they have not chosen the path of technology transfer by establishing joint ventures with foreign companies. From the point of view of the industry in China as a whole, it seems that domestic firms have significantly upgraded their technological capabilities. This is in contrast to R&D within the foreign production joint ventures which remains mostly within the realm of advanced development.

Therefore it can be argued that, in this industry, domestic corporate R&D is becoming more important as an engine of technological capability building than international technology transfers through joint ventures. This is matched by the observation that domestic firms are increasingly manufacturing products that have not yet reached technological maturity (such as DWDM systems).

Table 7.1 Technology Acquisition Through Self-Development

Pros	Cons
• More control over the results of R&D, and potentially greater potential return on the investment. This is due to the domestic firm not having to worry about competing against a foreign partner's own products in international markets. • Lower intellectual property-related costs. • Freedom to decide what products to develop according to the company's own interests.	• Greater allocation of resources (HR, financial, etc.) in order to catch up technologically. • Greater uncertainty of success. • Longer time to market (self-development takes time!). • State funding may tie company to certain obligations (such as sharing intellectual property developed by the company).

Table 7.2 Technology Transfer Through JVs

Pros	Cons
• Relatively quick time to market. Can quickly capture market share. • Ability to focus resources on manufacturing know-how, rather than R&D, in order to place new products on the market.	• Do not gain strong capabilities in new product design as the focus is mainly on assembly/ manufacturing. • Very limited opportunities to create a learning environment. Management does not gain experience in running a new product development program (project execution skills).

7.3 Product Development Strategies and The 'Configurational' Nature of Communications Technology

In his book, Shen (1999) gave an account of two paths in the acquisition of SPC switching equipment technology by Chinese industry. One path involved a formal technology transfer process through a joint venture (Shanghai Bell), the other was through self-development by a set of entrepreneurial state-owned factories and research institutes. One of Shen's central arguments was that Chinese firms were able to draw upon the 'configurational'[29] nature of communications technology to develop their own version of an SPC switching system.

The advantage of a configurational technology, described in *Chapter 2*, is that recipients are able to access certain parts of this technology according to their own capabilities, and it is thus adaptable to local circumstances. Therefore, a company could have the capability to understand certain aspects of a technology while leaving others as a 'black box' without necessarily compromising its ability to produce the particular piece of equipment. In the example described by Shen, Chinese firms were able to produced their own version of an SPC switch by combining their technological capabilities with components and modules available from foreign sources. They did not have to understand how to make everything themselves. As the domestic firms' capabilities improved, they were able to add features and upgrade their technology accordingly, gradually opening the 'black boxes'.

The second hypothesis, therefore, proposes that the model of technology acquisition that involves leveraging the configurational nature of technology is still important today (if not more so) for the product development paths of Chinese firms. This hypothesis can be tested in two ways. The first way is to look for evidence of this configurational characteristic within the communications industry; the second is to observe the behavior of the firms (i.e. whether they take advantage of this characteristic or not).

How Configurational are Communications Technologies?

As explained in *Chapter 2*, a 'configurational' technology allows development costs to be reduced by drawing upon existing component technologies. These can be selected according to the particular uses of the final product. As illustrated by the case studies, a technology can be configurational at different levels. At the product level, a particular piece of equipment can be configurational such that relatively standard components, modules, software, etc. can be obtained from various sources and used to assemble the final product. At the level of communication *systems*, these can be configurational such that pieces of equipment are compatible enough to be integrated together as a network[30].

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[29] The term 'configurational' with respect to a technology can also be taken to signify qualities of modularity, inter-operability or compatibility of component elements.

[30] The latter definition is an expansion of the framework originally used by Shen (1999) to accommodate observations made from the behavior of the case study firms.

Evidence from Technology Trends within the Industry

There are strong indications that the communications industry is tending towards greater configurability at the level of equipment, as well as at the level of the network.

Evidence for the increasingly configurational characteristic of communications equipment can be observed from international trends in the industry structure, described in *Chapter 3*. The optical communications industry illustrates best the sharper definition that is occurring between systems providers on the one hand (the OEMs), and suppliers of components, modules and sub-systems on the other. Although the large, branded, OEMs still maintain certain capabilities to produce proprietary components for their systems, they are increasingly relying upon a host of suppliers. This general division of labor is also reproduced to a certain extent in the data communications and mobile communications industries. The significance of this is that it signals a greater need for standardization, configurability and compatibility between components since suppliers provide these to various OEMs[31].

Configurability at the level of the network system is also an emerging trend, as described in *Chapter 3*. Increasingly, products and systems provided by different equipment vendors need the ability to inter-operate across the network. This is being driven by the fact that the types of services provided by telecom operators are expanding (due to the convergence of voice and data), and hence one equipment vendor cannot supply every single product needed by a service provider. As telecom operators increasingly need to purchase equipment from various vendors, the latter's products have to become inter-operable so that they may be integrated in a coherent manner. Configurability at the level of the network is an expansion of Shen's original definition, however it is very relevant to Chinese firms as they have gone from producing mainly one type of equipment (switching systems), to providing entire optical, data and mobile communications systems.

Evidence from Case Study Observations

The best indication that Chinese firms may be taking advantage of the configurational nature of communications technology in order to better compete, can be found in the behavior of the case study firms. One such indication is their changing product development strategy – more alliances with suppliers – as well as the types of products they are purchasing from suppliers.

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[31] A map of OEM-supplier relationships presented in *Appendix 2a* shows that the large systems providers are purchasing and integrating components and sub-systems that are available on the market from various suppliers. This corresponds to Shen's notion of a configurational technology.

The changing product development strategy of ZTE was discussed in the section above dealing with corporate R&D. Initially, the company's objective was to develop most of its products in-house. However, two factors seem to have pushed ZTE's management to re-think their product strategy:

- Customers (telecom carriers) demand end-to-end solutions from their equipment suppliers[32]. Although ZTE is one of the largest domestic equipment companies, it does not have the full line of products necessary to fulfill these demands.
- Communications technology changes rapidly and thus many products either soon become obsolete or lose much of their profit margins. At present, ZTE does not have the resources and know-how to stay technologically competitive in every component, module or piece of equipment that is included within the telecom systems they provide.

Because both ZTE and Huawei do not rely on technology transfers from foreign partners in order to introduce new products, they have begun to increasingly rely upon suppliers. These suppliers either provide them with the products they do not produce in-house, or provide them with the *platforms* that enable their products to be made compatible with those of other firms. The fact that telecom equipment can to a large extent be mixed and matched (subject to certain compatibility issues), is evidence of the configurational characteristic which domestic companies are taking advantage of. This is very reminiscent of the successful development by domestic companies of SPC switching systems in the early 1990s.

Chapter 6 describes various supplier relationships in which foreign companies provide Huawei and ZTE with pieces of equipment. The Chinese firms then integrate these into the systems they sell. For example, according to one manager at Huawei, the company incorporates a LAN switch manufactured by Intel into its data networking suite of solutions[33]. Intel acts as an OEM to Huawei, which actually puts its own brand on their piece of equipment. In another case, an interview with the sales representative of a well known U.S. company revealed that it was in discussions with Huawei to provide the Chinese firm with 'Layer 3' switching equipment[34]. According to the salesperson, Huawei does not currently have the capability to produce Layer 3 switches (although it needs to provide them to its customers), and thus it is looking for potential suppliers of this equipment.

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[32] For example, in the short term, PTAs and China Unicom branches have a preference for turn-key delivery of cellular systems. This allows networks to be installed and revenue to start flowing as fast as possible, and operators to meet the extraordinary consumer demand for cellular services (Pyramid Research 1999b). This demand for end-to-end solutions will probably expand to other areas of telecommunications, hence posing a challenge for domestic vendors who have not developed the full range of products necessary. Thus cooperation agreements with other foreign suppliers for discrete pieces of equipment or components are important.

[33] Interviewee #6.

[34] Because these discussion had not been made public at the time of writing, the name of the U.S. company has been withheld.

The technology supplier relationships described in *Chapter 6* contain several elements that reinforce the Chinese companies' abilities to leverage the configurational nature of communications technology. For instance, both ZTE and Huawei have made deals with Motorola to adopt its 'Smart Network' platform and to design their equipment according to this platform. This will allow them to integrate their products with those of other companies which have equally adopted Motorola's platform. Similarly, Huawei and IBM signed a collaborative R&D agreement to make their respective equipment more compatible. Examples also exist in which the Chinese companies have adopted *software* platforms provided by foreign firms, thus opening their hardware to greater compatibility with other companies' equipment[35].

Benefits Arising from the Configurational Nature of Communications Technology

R&D Strategies for the 'Self-Development' of Products

As indicated by the new product development strategy of ZTE, domestic companies may be focusing their R&D efforts on certain core products and capabilities, rather than spreading themselves too thinly. However, Huawei and ZTE currently provide a wide portfolio of products to their customers. This has implications for their R&D management, since keeping up-to-date across these technologies is unrealistic for such relative newcomers. Thus, by drawing upon the configurational nature of communications technology, domestic firms can focus limited R&D resources onto particular core technologies, while purchasing the rest from suppliers. This allows the Chinese firms to respond to their customers' needs while efficiently coordinating investment in their own technological capabilities.

Improved Time-to-Market and OEM Relationships

Clearly, domestic companies derive important commercial benefits from the fact that the technology is configurational. By using suppliers to provide them with key components, equipment. or software, allows these firms to considerably shorten their time-to-market. They do not have to invest months or years of R&D to produce such products and instead are able to integrate them with what they currently manufacture in-house.

The emphasis on compatibility between various communications equipment also enables Chinese firms to enter into two-way OEM relationships. On the one hand, foreign companies can act as OEMs for a Chinese company (e.g. Intel supplying equipment to be integrated into Huawei's systems). On the other, Chinese equipment producers can act as OEMs to foreign firms (e.g. Huawei supplying GSM mobile switching equipment to Motorola). ZTE has also recently held successful inter-operability tests between its own CDMA switching equipment and the CDMA mobile systems of Ericsson and Nortel[36]. Thus it could potentially act as an OEM to these two companies.

[35] These include the agreements between Huawei and VocalTech (for voice-over-IP applications), and Intel (for its Internet Exchange Architecture platform).
[36] Information from press releases on ZTE's web site.

The adoption of certain software and hardware platforms by Huawei and ZTE, enabling their equipment to be compatible with that of other companies, increases the possibilities for engaging in these two types of OEM agreements. Either way, Chinese firms have the opportunity to expand their market.

Implications for Chinese Industry

The above discussion allows us to answer the second hypothesis in the affirmative. Firstly, communications technology is in certain areas tending towards greater configurability. Secondly, the case study firms seem to have begun to take this more into consideration in their product development planning, given limitations in technological capabilities. Hence they are entering into numerous relationships with suppliers, some only arms-length, while others are closer partnerships (this is the subject of the next section).

Therefore, the domestic firms are leveraging the configurational nature of communications technology to help them compete on the market. In parallel, they are also managing their R&D efforts in areas in which they wish to develop a competence. It remains to be seen through further investigations, however, whether this is a trend pervading the domestic industry[37].

7.4 TECHNOLOGY SUPPLIER RELATIONSHIPS

The advantages of a configurational technology can only be realized if required components and equipment can be readily obtained from foreign suppliers. Hence a third hypothesis was proposed: that supplier relationships with foreign firms are important sources of knowledge and technology for Chinese companies within this industry. These suppliers provide components, modules or 'platform technologies'[38] that have a direct bearing on the technological competitiveness of domestic firms' products.

Technology Supplier Relationships and Their Role in Technological Catching Up

The beginning of this chapter analyzed the importance of the case study firms' internal R&D efforts to make their products technologically competitive. We have also established that the configurational nature of communications technology has enabled Chinese firms to rely upon foreign suppliers to provide them with technology.

[37] Preliminary research indicates that Datang has been recently engaging in similar supplier relationships as Huawei and ZTE.

[38] A platform can be either a software or hardware-based environment around which other software or hardware is designed. It provides a ready-made framework of standards and interfaces that other companies can use to design their own value-added products. One such example is Microsoft's Windows operating system platform.

We therefore now turn our attention to the role of suppliers in this process, and how they have aided Huawei and ZTE to 'self-develop' their products.

The two case studies in *Chapter 6* show that Huawei and ZTE engage with a variety of different suppliers. These have been characterized together as *technology* supplier relationships in order to encompass the notion that they provide the Chinese firms with technology, encapsulated in various forms. The types of technology supplied to the two domestic firms range across a spectrum, which includes:

- equipment and components (where the technology is contained within, but not readily dissociated from, the physical hardware);
- design capabilities (often based upon a platform provided by the supplier);
- consulting services related to product development (managerial know-how); and
- technical tools for improved manufacturing and product development processes.

The first three points deal specifically with acquiring technologies that ultimately get incorporated into the firms' products, either physically or through improving the management of R&D. Therefore they contribute to the competitiveness of the companies' products. The first three forms of technology supply represent relationships that are progressively more empowering (in terms of upgrading the recipient's internal capabilities). The first involves arm's-length transactions – simply purchasing technology as a 'black box'. The second provides the recipient firm with the design capabilities to develop products or components based on a pre-developed platform[39]. The third strengthens the recipient's internal management at a deeper level of the R&D process, although it is more general and not related to a specific technology. The last point stands somewhat apart from the rest given its focus on production. Nevertheless, this is obviously an important aspect of a firm's broader technological capabilities.

The Role of Suppliers in Technological Catching Up

The evidence from the case studies indicates that suppliers have had two potential impacts upon the domestic firms. The first is that they have enabled Huawei and ZTE to 'punch above their weight' in relation to their own technological capabilities. The second is that they may have to a certain extent contributed to the firms' R&D capabilities.

Chinese firms' ability to punch above their weight refers to the way in which they have been able to incorporate their suppliers' technology into their own products without having to necessarily do all the groundwork themselves. At the simplest level, this is illustrated by the purchasing of components and sub-systems from foreign sources, some of them leading international suppliers. For example, SDL Inc. (now part of JDS Uniphase), has supplied Huawei with components for use in the latter's DWDM systems. Similarly, ZTE has also been purchasing key high-tech components for its DWDM

[39] The supply of key components such as microchips is often accompanied by the supply of a platform. Generally, this is done so that the recipient firm may design its equipment in a manner that is compatible with the supplied components and in accordance with the standards used by the supplier.

systems from foreign sources[40]. These are the kinds of arm's-length transactions described above.

A closer form of cooperation between the Chinese firms and their suppliers has centered upon the use of specific platform technologies for developing components and systems. In this case, foreign companies have provided Huawei and ZTE with ready-made platforms upon which to design specific components. The platform is the technology provided to the domestic firms. They, in turn, are able to add value by using these platforms to create new products. Huawei and ZTE therefore have not needed to invest resources in developing these platforms. However, they are able to reap benefits that come from being able to customize the design of key components for their equipment in a cost-effective manner. These self-designed components are also comparable in quality to those used by competitors in the industry (although their technological performance depends on the user's design skills).

The contribution which suppliers have made to the case study firms' R&D capabilities stem mostly from the provision of these platform technologies. This has often entailed setting up joint-R&D labs for using the platform, providing training and technical manuals, dispatching technicians to help with trouble-shooting and debugging, etc. Thus foreign suppliers have contributed to (and even established) the Chinese firms' R&D activities directly related to these platform technologies. It can be assumed that a certain amount of knowledge is transferable to other similar R&D activities within the companies and that their researchers' understanding is enriched by these exchanges. For example, as part of its agreement to use Motorola's ASIC design platform, Huawei's own ASIC design team (said to be the largest and most successful in the industry[41]), will work closely with the supplier to implement it. Nevertheless, further investigations are needed to determine to what extent suppliers contribute to R&D capabilities beyond the specific applications they provide.

The third type of technology supply mentioned above relates to consulting services provided to improve R&D processes at a more general level. This is illustrated by the training Huawei received from IBM on implementing 'integrated product development processes' on how to manage R&D within the company[42]. Although this may be a unique case (so far), it is nevertheless an indicator of the types of services that domestic firms can draw upon to improve their performance. One interviewee stated that one of the key factors that will influence the success of domestic firms will be their ability to manage R&D effectively[43].

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[40] Interviewee #4.
[41] Liu (2000b).
[42] Exact details of what this training involved and how it has changed Huawei's R&D processes could not be obtained.
[43] Interviewee #12.

Lastly, the fourth type of technology provided by suppliers relates to management tools and equipment for improving production efficiency. For example, these may relate to improving software design efficiency, such as Intersolv's PVCS tool; or improving the design and layout of printed circuit boards, such as PADS' software. Both of these were purchased by Huawei and included consultation, maintenance and product upgrades on the part of the suppliers. However, although production is important, these types of supplier relationships are tangential to the main issue of improving Chinese companies' product technologies, and are thus beyond the immediate scope of this thesis.

Trends in the International Structure of the Communications Equipment Industry

The trends in the global communications industry described in *Chapter 3* raise several questions with respect to the industry in China. Although China is the largest and, currently, the most important market for Huawei and ZTE, these companies aspire to become important global players. Therefore changes that are occurring in the international industry structure – both for equipment vendors and the telecom carriers they sell to – will ultimately affect them. Even within their home market changes are beginning to occur. Although the government has officially banned foreign participation in the telecom service sector prior to WTO entry, already one exception has emerged in Shanghai which has the State's blessing (or at least that of individuals with sufficient influence). Chinese firms therefore need to pay attention to where the industry is headed (technologically as well as structurally).

One trend that seems to be favorable to the Chinese firms is the vertical disintegration that is becoming apparent between the OEMs (the systems providers), and the component suppliers. As explained in *Chapter 3*, this has been caused by the fact that, in some sectors of the industry, technological change is taking place more rapidly at the component level than at the systems level. As the economics of the systems manufacturing business (core competencies being in software and systems engineering) diverges from that of the components manufacturing business (R&D driven), an increasingly large supplier base is emerging (as well as merging). Furthermore, the most cutting edge, next-generation technologies are to be found within a host of smaller, privately held companies and start-ups.

The vertical disintegration of the communications industry, producing a base of component and module suppliers, is particularly advantageous to Chinese companies such as Huawei and ZTE. Because the development of certain key components is an R&D-intensive process – requiring specialist skills in short supply even in the U.S. – the fact that these could be purchased rather than made internally is good for Chinese equipment firms. Furthermore, the greater component integration that these suppliers are beginning to provide is also potentially desirable as these manufacturing processes involve a lot of technical precision and are difficult to carry out[44]. Thus, purchasing

[44] In the optical components industry, for example, some manufacturing processes are so complex that suppliers who have mastered efficient ways of carrying them out treat these methods as trade secrets.

modules rather than raw components might be able to help Chinese firms improve the quality of their systems and reduce manufacturing costs.

Changes in the international industry structure have produced some models that Chinese companies could possibly emulate. Sycamore Networks (in optics) and Avici (in Internet routers) have followed strategies of outsourcing as much as possible. As relative newcomers, this has allowed them to rapidly build market share by concentrating on their core competencies and outsourcing component and module manufacturing. If the industry structure facilitates the outsourcing by Chinese companies of certain aspects of product development, they could then focus their limited resources on building up the core technical competencies that are needed for them to compete.

Lastly, the fact that technological innovation mostly lies within the component/module manufacturers in Silicon Valley (and other centers of high tech innovation) is another industry characteristic that Chinese companies could harness. Domestic equipment vendors could try and tap into this technology and incorporate it into their products, a strategy that is starting to be facilitated by international consulting firms[45].

Implications for Chinese Industry

To answer the third hypothesis, the discussion above indicates that international supplier relationships *are* having an important positive impact on the technological competitiveness of Chinese vendors' products. However, there are several issues that need to be further addressed.

Firstly, it is safe to assume that the key factors that differentiate foreign companies in the international market will also be expected of Chinese companies. These are the core competencies that Chinese firms need to master themselves, and include systems engineering, software engineering and ASIC design (depending on the particular industry segment). The technical superiority of these competencies determines the success or failure on the market. Suppliers cannot be depended upon to provide these, therefore Chinese vendors must rely on their own investment in R&D.

Secondly, although cutting edge component technologies as well as equipment can be purchased on the market from a growing and globalizing supplier base, Chinese firms will probably have to compete with the dominant foreign firms for limited supplies. Whenever there are supply constraints, suppliers will tend to ration according to the importance of their customers. Amsden (2000) describes the challenge that Taiwanese electronics firms have had in attracting suppliers' attention, something that was achieved by gaining sufficient scale in their operations. Similarly, Chinese firms will have to signal to potential suppliers by becoming important players in the Chinese market. There are already indications that successful signaling by Chinese vendors is very important for attracting suppliers. In an interview with a sales representative of a U.S. firm that was in discussions with Huawei over supplying it with Level 3 switches, the representative

[45] Interviewee #21.

described reasons for choosing this company over other domestic firms. He stated that Huawei was a good choice of customer "due to its leading position in the Chinese industry, its dynamic approach to the market, and its understanding of the technology". Foreign suppliers, particular smaller ones with limited production capabilities, want to 'bet on the right horse' in order to penetrate the Chinese market. Thus the factors mentioned by the sales representative are very pertinent.

Lastly, although the industry is increasingly becoming vertically disintegrated, having an in-house capability in component design and R&D may be an important differentiating factor. Nortel, for example, still retains such capabilities although it is increasingly outsourcing to suppliers. The importance of this capability lies in the ability to generate or spot technological breakthroughs and thus increase the chance of reaping monopoly rents through technological leadership. It is perhaps too early to expect this kind of technical expertise within Chinese enterprises, however they may need to substitute for this in some way. This could be achieved by establishing closer relationships with organizations that perform more basic kinds of R&D, such as domestic university research institutes, or perhaps even technology start-ups in foreign countries (e.g. the U.S. or U.K.).

7.5 An Assessment of Government Policies

Having answered the hypotheses above, this section now evaluates the impact that Chinese government policies have had on the telecom infrastructure equipment sector. However, at this point it is appropriate to express a caveat, which is that the information on policies described in *Chapter 5* is somewhat incomplete for two reasons. The first is that the material used was only that which could be obtained from sources published in English. The second reason somewhat mitigates the first, and is summed up in the words of a government official who was interviewed: "Most people know the policies that the government publishes. However it is the policies that aren't published which are the most important!"[46]

Policies Encouraging the Domestic Development of Product Technologies

Policies Directly Aimed at Technological Improvement (Technology Policies)

The government's two-pronged effort at encouraging technological development through foreign technology inflows as well as the building of domestic capabilities (also known as "walking on two legs") is evident in the policies discussed in *Chapter 5*.

Firstly, with respect to foreign technology, the government's technology transfer policies were aimed at harnessing the strong interest of foreign companies to invest in China. In the telecom equipment sector, the Chinese government strongly encouraged foreign companies to establish manufacturing joint ventures with local state-owned factories.

[46] Interviewee #17.

The impact that these policies had on the sector as a whole is somewhat mixed. In terms of transferring manufacturing technology, these JVs have probably been quite successful. BISC (a Siemens JV manufacturing switches) for example, claims to have localized 100% of manufacturing[47], and this has also been acknowledged by officials within the MII[48]. However, the government has expressed some misgivings about the track record that JVs have had in transferring the technologies of the actual *products* they are manufacturing (i.e. the capabilities to understand and design these technologies from scratch). This issue is discussed in more detail below.

With respect to the case studies of Huawei and ZTE, it is not likely that JVs have had any *direct* impact on the companies' technological capabilities. There is no indication in the corporate history of either firm that they have been involved in joint ventures with foreign companies. Rather, they have developed their manufacturing capabilities in-house or bought the services of foreign organizations to help them develop these[49].

Secondly, with regards to government policies directed at improving the technological capabilities of the domestic industry, these have consisted of two types: national plans and more targeted programs. As described in *Chapter 6*, ZTE has participated in several of the government's national programs. Under a 'China 863 Plan' initiative, ZTE gained the capability to develop an Optical Add/Drop Multiplex (OADM) systems – an integral part of an optical transmission DWDM system. This was done in cooperation with other companies and university institutes. Under the same Plan, ZTE is also involved in the development of third-generation mobile communications. The company's participation in these initiatives allows it to pool its expertise with that of other domestic players and thus develop technologies which might take longer to create on its own. ZTE has also been a beneficiary of the government's 'Torch Program' which encouraged the spinning off of government research institutes and their merging with newly-formed 'science and technology enterprises'. Thus, from the perspective of individual firms, the government's technology capability-building programs have had some successful outcomes.

From a sector-wide point of view, the national plans also seem to have contributed to upgrading China's technology base. The 'Optics Valley' centered around the Wuhan East Lake HiTech Development Zone, discussed in *Chapter 4*, can also be seen as a testament to the government's efforts in promoting basic research in advanced areas of telecommunications. The research expertise developed within these areas has found its way to companies such as ZTE and Huawei who have employed key research staff from institutions in Wuhan[50]. Furthermore, individual cases such as that of Fujian Casix Laser[51] also demonstrate that significant expertise has grown within the domestic industry. In the case of Casix, the company has developed very advanced techniques in fiber-optic component processing and manufacturing, to such an extent that JDS

[47] Interviewee #9.
[48] Interviewee #18.
[49] Huawei, for example, has cooperated with the German National Research Institute of Technology to study the application of production processes and quality control.
[50] Interviewee #4.
[51] See *Chapter 4*.

Uniphase – one of the most important global optical component manufacturers – recently decided to acquire it.

The Chinese government has also stimulated technological development through incentives and performance requirements for domestic companies. In granting science and technology enterprises (of with telecom equipment manufacturers are a subset) a special legal status, the government obliged them to meet certain requirements. These enterprises were granted rights to establish themselves in special high technology development zones, have benefited from sophisticated tax concession schemes designed to promote innovations in product and processes, and have been recipients of preferential loans and other financing packages. In return, the requirements expected of these enterprises have included the percentage of technology personnel employed, the percentage of sales contributed by new products, the percentage of products exported, and the allocation of retained earnings. This demonstrates that the government hasn't only relied on the market to provide the right signals, but has been active in directing investment in particular areas.

Lastly, the government has been pushing very strongly the adoption of the latest communications technologies in order to provide a modern infrastructure for economic development. The sophistication of the Chinese market can be gauged by the fact that the country is starting to face key decision points on a schedule not dissimilar from that in the West. For example, the Chinese government began thinking about how to allocate 3G mobile licenses (and developing its own 3G mobile standard) less than a year after this was carried out in Europe[52]. Furthermore, the telecom equipment market has been relatively open to competition from foreign companies since the inception of the economic reforms, particularly in the higher end of communications technologies. All these factors provide a challenging environment for a nascent industry. However, by plunging domestic companies in the 'deep end', the government has not allowed Chinese firms to be complacent about their own pace of technological development. Nevertheless, it has at the same time provided a framework to improve the domestic industry's competitiveness.

Policies Designed to Stimulate Investment in Product Development and Manufacturing by Domestic Firms

In addition to its policies targeted at domestic technology development, the government has also tried to ensure that market opportunities exist for Chinese companies. This provides them the prospect of a return on their investments to upgrade themselves. To this end, it has instituted 'buy local' policies whereby national carriers and local PTAs are strongly encouraged to purchase from domestic companies. These initiatives have been very successful as judged by the results of several 'coordination meetings' in which domestic service providers and equipment manufacturers were brought together under the aegis of the government to sign purchasing agreements for switching and mobile systems[53]. The government has also been instrumental in extending financing packages

[52] Interviewee #20.
[53] See *Chapter 4*.

to domestic equipment vendors and their PTA customers to encourage the purchasing of local equipment.

Furthermore, the Chinese government's efforts to reform the telecom services sector has the parallel effect of enlarging the market for both domestic and foreign firms, a fact that has been readily recognized by Chinese firms[54]. However, the resulting increase in competition in the services sector will hold both advantages and disadvantages for domestic companies. On the one hand, domestic firms can play on their competitiveness in price to win contracts. On the other, the greater degree of independence, accountability and transparency in decision-making on the part of national and local carriers may weaken the cosy relationships established between domestic equipment vendors and their customers. Chinese equipment companies will need to become more competitive on the strength and quality of their technology – something which they are still struggling to achieve despite their efforts[55]. The greater attention given to foreign markets by domestic vendors has been partly attributed to their desire to prove themselves to their customers back home, demonstrating their capability to deliver large-scale, reliable communications systems.

Lastly, the government's influence in establishing favorable market conditions for domestic firms is evident in how it manipulates the creation of new markets and the setting of technical standards. For example, one of the factors influencing the timing of CDMA implementation by mobile telecom carriers is the extent to which domestic firms have the capability to produce CDMA systems[56]. The government wishes to ensure that Chinese firms are in a position to gain market share and do not find themselves unable to compete, as happened in the GSM market. With respect to technical standards, informal government policies are designed to give domestic firms an inside track on the development of specific communications standards. Since foreign companies need time to adapt their products to Chinese standards, this give Chinese firms an edge on the competition. These practices, however, will certainly be called into question upon China's accession to the WTO (if and when this occurs), as they constitute non-tariff barriers to trade which are illegal under the GATT treaty.

Policies Encouraging Technology Diffusion

Another aspect of the Chinese government's technology development policies has been its efforts to diffuse technological learning across the industry. Particularly with regards to Chinese-foreign joint ventures, the goal of localization policies was to promote technological (and economic) spillovers from foreign direct investment in the country. According to government and industry sources as well as the literature, however, the success of these policies is somewhat debatable[57].

[54] Interviewees #2 and #15.
[55] Interviewee #12.
[56] Interviewees #1 and #10.
[57] See the discussion at the end of this section.

In a more general way, the loosening of employment restrictions has probably had one of the most beneficial effects on the diffusion of knowledge. As skilled labor can relocate to where demand for these skills is most valued, they take the knowledge gained and transfer it to new organizations. In this respect, the localization of labor (as opposed to manufacturing) in foreign JVs has had a positive effect, as managers and technicians trained in these companies eventually leave and join domestic firms. In the case of Shanghai Bell, the company was considered as a 'big school' that fostered a great number of qualified engineers. Every year, around 3 to 4 percent of the engineers left the company to work elsewhere while new ones joined (Shen 1999). The mobility of labor has also helped to redistribute the fruits of government-funded basic research in numerous areas of communications technologies. For instance, the leading domestic manufacturers such as Huawei, ZTE and Datang have actively wooed away engineers from the Wuhan Research Institute (WRI), as these are highly prized for their knowledge of optical communications[58].

General Government Policies Impacting the Telecom Equipment Sector

There are numerous government policies that have had an important impact on the telecom infrastructure equipment industry, although they were not designed to target it specifically. Some of these have been mentioned above, such as the telecom services sector reforms and human resources policies. One area which has been repeatedly mentioned by individuals interviewed has been that of equities markets and corporate governance.

The listing of ZTE and Datang on the Shenzhen and Shanghai stock exchanges was very useful to them as sources of capital, however the stock market mechanism is still immature and not being used to its full potential. For example, the trading of stock between companies can be a way of aligning interests and promoting cooperation between domestic companies, however not many telecom equipment companies are listed in China[59]. Furthermore, the growth of domestic telecom equipment firms has mostly been organic[60] as they are not able to use the stock markets to merge with and acquire other companies. The issue of corporate governance also affects the sector as many telecom equipment companies are state-owned or have complex management and ownership structures. Thus it can be very difficult for entrepreneurial companies to acquire each other when there is no transparent or convenient means of buying and selling ownership rights. This leaves the government as the main actor capable of pushing these deals through although its judgement may not always be the best for the companies concerned. Given an appropriate framework for trading equities, such decisions are probably best delegated to the firms involved.

[58] Interviewee #4.

[59] Interviewee #3.

[60] Apart from initially when ZTE and Julong, for example, were created out of the government-orchestrated merger of several factories and research institutes.

The Role of Chinese-Foreign Joint Ventures in Upgrading Domestic Product Technologies

As mentioned above, there is some debate about the technological benefits derived from foreign manufacturing joint ventures in China's telecom equipment sector. Because technology transfer through JVs has been a central theme of government (and specifically MPT/MII) policies regarding technology acquisition from abroad, it is appropriate to devote some attention to these structures.

The example of Shanghai Bell discussed by Shen (1999) provides a good first brush on several of the issues, the first being that of component localization. Shen describes how Shanghai Bell found it necessary to game the system by massaging the calculations to determine the percentage of localization achieved. Furthermore, after several years most of the items localized were still relatively low-tech components due to the low levels of domestic investment in the production of higher technology components. Localization was finally achieved when it made business sense (often as a result of changes in the macroeconomic environment), not because of government pressure to transfer production technologies. In the words of a Chinese General Manager of Shanghai Bell: "When government is pushing us to adopt import substitution, well we will do it, as long as the interests of the company are not compromised." This also indicates that government investment is essential if localization of certain key components (such as microchips) is to be achieved. To this effect, the MII is promoting the development of 'fundamental' industries, including semiconductors[61]. This clearly benefits domestic firms as well.

Similarly, an executive from a major U.S. telecom equipment company in China who was interviewed stated that the firm's advertised commitments to localization and local purchasing were all done according to what made business sense. It would not, however, localize many of the high tech components that it supplied because it would be too costly to do so. Another example is that of the Beijing International Switching Systems Corporation (BISC). In this case a manager described that, although equipment assembly was 100% localized, the key components were still purchased from Siemens (the foreign partner)[62]. Therefore JVs seem to still be highly dependent on their foreign partners for key technologies which, for various reasons, have not been transferred as part of the agreement. These examples demonstrate that localization does not necessarily equate with the transfer of advanced product technologies if these do not make economic sense to the foreign partner. Therefore the government's ability to manage the substance and timing of technology transfer can be very limited.

The second issue, that of the transfer of product technologies, is also neatly summed up by Shen: "It is common knowledge that, through technology transfer, the technology supplier wants to create markets rather than create competitors" (Shen 1999). The significance of this is that the foreign partner may agree to transfer manufacturing technologies as well as carry out the necessary R&D to adapt products to local conditions, however it will not purposefully transfer its core product technologies to the

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[61] Interviewee #18.

[62] This is one of the ways by which Siemens makes a profit on the venture (interviewee #9).

domestic partner. Several sources agree that domestic firms have become excellent at manufacturing through JV agreements. However, on the whole they do not seem to have gained significant innovation capabilities nor have they gained the ability to develop on their own the equipment that they manufacture[63].

When judged necessary by the foreign partner, JVs will tend to be structured in such a way that the foreign company does not lose control over its core product technologies. For example, in the case of Nortel, this has been achieved by taking a majority stake in all its JVs so that its share of ownership never falls below 55% (the range being from 55% to 90%). Nortel's production JVs in China are considered to be good at manufacturing, and those JVs which carry out R&D deal mainly with product adaptations to Chinese market requirements. If Nortel did not have control over its JVs, it would provide less support in transferring technology due to concerns regarding intellectual property protection[64]. However, it seems that majority control is not absolutely necessary for the foreign partner to exert its influence. In the case of BISC, Siemens has a 49% stake, yet it directs the JV's decisions regarding the sourcing of components (the JV has to stick to a list of approved vendors), and has the ultimate say in important decisions. What really matters therefore, are the details of JV agreements and the effective power that the foreign partner wields from being the source of technology to the joint venture.

In summary, therefore, joint ventures with foreign telecom equipment manufacturers have probably not been very successful in transferring the know-how necessary for domestic companies to develop products themselves. Furthermore, it is not clear that this has ever been the intention of foreign JV companies. For the most part, JVs have been production-oriented and have successfully transferred the skills related to this type of operation. With regards to opportunities for learning skills related to new product development and innovation, these seem to have been at best limited – the objective being to replicate designs provided by the foreign partner. On the other hand, the joint ventures have been a good training environment for Chinese managers as well as engineers, many of whom have gone to work for domestic companies. Furthermore, the component and manufacturing localization initiatives of these JVs have certainly contributed to the general economic welfare of the sector.

This is obviously not a conclusive, nor a comprehensive, discussion of the impact of Chinese-foreign JVs on the domestic technology landscape. More in-depth studies would have to be carried out in order to gauge this. However, it does highlight some important issues. These provide a point of reference when assessing the achievements of 'pure' domestic firms in terms of their learning and innovation capabilities, as well as their contribution to the domestic industry.

[63] Interviewees #10, 17 and 18. See also Shen (1999).
[64] Interviewee #10.

7.6 *DISCUSSION*

Four Factors Contributing to the Technological Competitiveness of Domestic Firms

Having analyzed the research results and addressed the hypotheses, we can now attempt to answer the main thesis question: how can Chinese companies compete against foreign firms in the high-end technology segments of telecommunications equipment? *Figure 7.1* summarizes the key factors which contribute to the technological competitiveness of Chinese firms in product technology.

Thus, four factors have been found to contribute to the technological competitiveness of domestic firms:

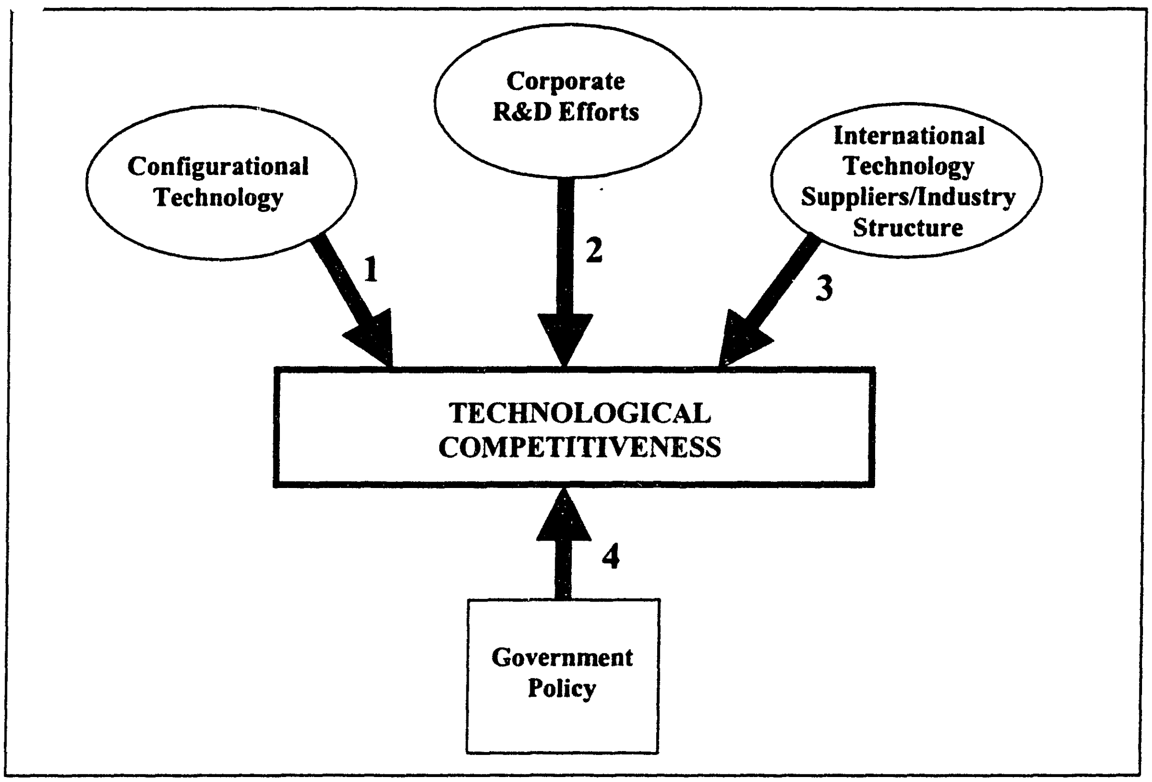
1. *Configurational technologies.* Domestic firms have been able to substitute their lack of technological capabilities in certain areas by drawing upon technology available on the market. In certain cases, they have reinforced the configurability of their systems by applying software and hardware platforms to make their equipment interoperable with that of other equipment vendors. This characteristic enables domestic firms to 'punch above their weight' in terms of technological capabilities.

2. *Internal R&D efforts.* Domestic firms have invested heavily in their own technological capabilities. This has enabled them to be close followers of the world technological frontier. Although they may not be innovators, their R&D activities seem to approach that which could be characterized as 'exploratory development'. The nurturing of these capabilities enables them to successfully unravel the tacit elements of high-end technologies and thereby self-develop equipment such as high-end routers and DWDM transmission systems.

3. *Technology suppliers and the international industry structure.* Domestic firms are able to leverage the configurational nature the technology due to the availability of component and subsystem suppliers in various segments of the communications industry. The growth in the importance of these suppliers is being driven by a number of trends within the industry, and the fact that it is becoming less vertically integrated. The ultimate effect is that domestic firms find themselves in an environment in which they are able to access technology through international supply chains.

4. *Government policies.* Government has been crucial in investing in the technological capabilities of the industry as a whole. Investment in the educational system and in national technology development plans have created a foundation of well-trained and experienced engineers. Performance standards, incentives and financing packages have been used by government to encourage the building up of technological capabilities within firms. Joint research programs and the encouragement of technology diffusion has enabled firms to acquire certain core technologies on which to build upon.

ure 7.1 Summary of Factors Contributing to Technological Competitiveness



Foreign Direct Investment

One important source of technology that hasn't been included in the framework above is foreign direct investment (FDI). In the two cases studied, foreign investment does not seem to have played a major role in the building of technological capabilities – neither Huawei nor ZTE, for instance, has been involved in a major joint venture with a foreign firm. Nevertheless, FDI has had an impact on the sector as a whole and should not be disregarded.

With respect to production JVs, however, these no longer seem to represent the major source of technological capabilities for domestic firms that was originally hoped for. The opportunities for technological learning within these companies is generally limited in scope to advanced development. Therefore JVs do not form an ideal training ground for engineers wishing to obtain the capabilities to manage R&D programs or undertake research that is more exploratory or basic in nature. These skills can only be obtained in domestic firms that invest in R&D (or within universities and government R&D institutes). Furthermore, if China accedes to the WTO, it isn't clear to what extent the government will be able to coerce foreign companies into establishing JVs, transferring technology, and localizing, beyond that which makes normal business sense.

Foreign direct investment through JVs or WOFEs may still be beneficial to the domestic industry by exposing it to new product technologies, and therefore new models to emulate. Nevertheless, the value of this will be lower if the latest foreign products can simply be imported (as they initially tend to be), or if domestic firms are able to obtain this information through their own efforts at tracking international trends in technology (as some of them already do).

The greatest value that FDI may have for the Chinese telecom equipment industry is investment in the companies that supply components and subsystems to the first tier equipment vendors such as Huawei and ZTE. This would overcome the potential shortages that arise as well as reducing the costs of managing international supplier relationships. There is a risk, however, that this may 'crowd out' the development of domestic capabilities in these areas (which the government regards as strategic). Other sources of value from foreign direct investment are the spillovers relating to production and project execution capabilities. Managers trained in foreign-invested companies would acquire valuable skill in these areas which they could apply when they move to domestic companies. This is particularly important since the lack of adequate management skills was one of the shortcomings of domestic firms that was most often quoted by interviewees.

Other Sources of Competitiveness

Although the focus of this thesis has been on the acquisition of product technologies, this is only one facet of a company's competitiveness. Clearly, other functions such as production, financial management, investment, sales and marketing, etc. are crucial to a company's competitiveness.

An issue particularly relevant to the Chinese context (as well as late industrializing countries in general), relates to corporate governance. Bad corporate governance can be a severe hindrance to a company's competitiveness, as the case of Julong seems to illustrate.

Limitations of the Study and Further Research

Huawei and ZTE are the two largest firms – and probably the most competitive – among the domestic telecom equipment companies. Therefore, they serve as very good subjects of analysis in trying to understand the factors that have contributed to the development of indigenous technological capabilities in China. Nevertheless, one of the major shortcomings of this research is that other domestic firms such as Datang and Julong have not been included. Datang, in particular, has been involved in the development of relatively advanced technologies, and its joint venture with Siemens to develop third generation mobile equipment is unique in the industry. Thus the generalizability and the completeness of the above analysis needs to be strengthened through further research.

With respect to applying the findings of this research to other industries or countries, several issues need to be considered. First of all, there are certain factors that are country-specific to China. One of these is the size of the home market, which has been an undeniable advantage to domestic firms. For example, government policies have been able to channel demand towards Chinese firms and this has been an important contribution to their growth. The size of the Chinese market has also provided the government with much negotiating power *vis à vis* foreign companies eager to gain a foothold. Another factor is that the Chinese government has put much effort in developing basic research in the field of telecommunications technology, thus producing relatively well-trained engineers and university graduates. Without this, it would probably have been much harder to develop technological capabilities at the level of the firm.

There are also industry-specific factors that should be considered. One issue that distinguishes this industry from other electronics or IT sectors is its relatively high R&D intensity. Unlike consumer electronics, the step changes in telecommunications technology can be very large and thus necessitate significant investment in R&D capabilities in order to keep up. Taiwanese notebook producers, for example, may only need to invest in advanced development capabilities (their competitiveness arising from manufacturing and integration capabilities). However, companies in the telecom equipment sector may not be competitive without investing in more exploratory or basic research given that the rules of second mover advantage do not necessarily apply to them (this is discussed in more detail in the last chapter).

8 Conclusions

The previous chapter analyzed the questions and hypotheses related to the research undertaken. The purpose of this chapter is to widen the discussion and understand how these findings correspond to existing theories and frameworks on industrial development in 'late-industrializing economies'[1] such as China. In particular, this will focus on the theory of 'second mover advantage', as discussed by Amsden and Chu (forthcoming).

The theory of second mover advantage was developed to explain the success of certain firms in late-industrializing economies. This theory proposes a set of characteristics that many of these firms (or 'latecomers') share, and which explain the basis for their competitiveness. Because the set of Chinese firms studied in this thesis fall under the category of latecomers, it is interesting to understand to what extend they follow, or diverge from, the models proposed by Amsden and Chu.

Second movers are, by definition, latecomer firms that operate behind the 'world technological frontier' and are therefore forced to compete according to a set of competitive advantages that are suited to their circumstances and the products they manufacture. "First movers" are firms typically located in industrialized countries that began to exploit a technology at the beginning of its product cycle – when it was still relatively new, subject to frequent and relatively radical innovations in its basic design or capabilities, and thus was able to reap monopoly profits (high margins) for its producers[2]. Second movers, on the other hand, are those firms that exploit *mature* products that are in the middle or end of their product lifecycle. Such products may still reap good profits in a market with growing demand, however, these are typically characterized by paper-thin margins. In both cases, the technology has become standardized and relatively well defined (more so the more mature a product is).

According to the theory, both first and second movers exploit the same *generic* set of advantages in that both are the first in their respective domains to invest in optimal-size plants, managerial and technological resources, and marketing. However, latecomers and first movers differ in the precise way in which these advantages are implemented, in accordance to their respective competitive positions[3]. More specifically, the theory

[1] In this context, late-industrializing economies are defined as those countries that possessed a history of manufacturing experience prior to World War II. These include China, Taiwan, S. Korea, Malaysia, Indonesia, and India in Asia; Mexico, Brazil, Argentina, and Chile in Latin America; and Turkey in the Middle East (see Amsden, 2000, for further details). These countries are variously known as "emerging economies" or "newly industrialized economies", although these definitions may encompass a wider set of nations of which they are a part.

[2] In this sense, a 'first mover' is not necessarily the *very first* company to create a technology, but is part of a *set of companies* that derive their competitiveness from being at the world technological frontier. A 'second mover' is a latecomer from a developing country that is the first to exploit a set of competitive advantages suited to the mature products they produce.

[3] See Amsden and Chu (forthcoming) for a detailed comparison of first and second mover competitive advantages.

behind 'second mover advantage' arises from five key themes: product maturity; economies of scale and scope; project execution skills; ramping up; and globalization and nationalization[4]. The extent to which second mover advantage theory applies to firms such as Huawei and ZTE will therefore be assessed according to these themes.

Product Maturity

There is a question as to whether the products manufactured by the case study firms are considered to be 'mature' or not. This can be a very difficult question to answer with respect to telecommunications equipment, one reason being that they are composed of both hardware and software. Some major changes in the functions of communications products can occur through new software development while not having to make fundamental alterations to the core hardware technology. Such software is often proprietary and subject to rounds of innovations, separate from hardware innovations[5], and can be complex and time-consuming to develop[6]. New life can be breathed into a piece of equipment or system through innovative breakthroughs in software design. Therefore, in this industry, whether a product is mature or not has to be very narrowly defined according to a specific product. This is a level of resolution which could not be obtained in the research for this paper but which should nevertheless be taken into consideration in future analyses.

Another aspect of communications technologies regards the way in which new products evolve. Although the basic technology of a piece of equipment may stay the same, product innovations introducing higher transmission capabilities, say, essentially start a new product cycle. For example, the basic technology for DWDM optical transmission (which both Huawei and ZTE produce), has been around for a few years, however the leading firms such as Nortel and Lucent are constantly improving on it in terms of higher transmission capabilities. Each of these could be considered a new product since capacity upgrades are highly valued by customers and thus reap monopoly profits for those companies able to produce them. Therefore, it is hard to say that "DWDM equipment is mature" – one would have to refer to a particular 'generation' of equipment and its related specifications. Again, this level of detail could not be obtained in the research undertaken, but is important to bear in mind in future work.

As described in *Chapter 4*, Chinese firms first began to produce mature products -- SPC switches – that were first introduced into China through joint ventures, notably Shanghai Bell. This same pattern was observed with respect to mobile systems (also mature products), although the development of Chinese systems seems to have taken longer than that of the switches, due to the higher complexity of the technology. Most recently, Chinese firms began to develop DWDM optical transmission systems. According to ZTE, the company developed their first commercially viable system in about a year,

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[4] See Amsden and Chu (forthcoming) for a detailed explanation of second mover theory.
[5] This make it different to the PC industry, for example, where the software is standardized (although still proprietary).
[6] Huawei, for instance, spent most of its time developing the software for its Internet routers, while the hardware architecture was easier to reverse engineer.

which seems like a very short amount of time given the high technology involved. Currently, domestic companies are attempting to develop third-generation mobile systems (on their own and through partnerships with foreign companies), which have not yet been widely commercialized in industrialized countries[7].

Economies of Scale and Scope

The theory of second mover advantage has mostly been applied to industries producing *consumer products* (such as electronics devices, cars, etc.) or *components* (such as semiconductors). In all cases, these are products which are suited to high volume production in assembly lines. This is in contrast to the industry examined within this thesis which develops equipment and systems for the telecommunications *infrastructure*[8]. Furthermore, not all of this equipment is suited to volume production but rather to *labor-intensive batch production* due to the difficulty of automation[9] (e.g. optical equipment), and the nature of the market. With regards to the market, it is composed of a relatively low number of telecom carriers and/or business enterprises (compared to the mass market), depending on the product, and the equipment is usually built-to-order and in accordance to different customer specifications. These characteristics are inherently unsuitable and inefficient for high volume production (Garvin, 1981).

Given the above observations, it is not clear to what extent economies of scale in *production* play a role. Obviously there is a certain plant size of minimum efficiency[10], however it is not certain that this should be much larger than that found in "first movers" given that high volume production is generally not applicable to infrastructure equipment. Second mover theory also posits that scale is important to many latecomers as a signaling system to foreign companies in order to win OEM and ODM contracts (as Taiwanese IT firms have). However, the Chinese telecom equipment firms considered in this research mainly sell products under their own brand and thus do not necessarily seek OEM contracts. In fact, some foreign companies serve as OEM/ODMs to the Chinese firms (e.g. Intel and IBM). This is probably due to the fact that Chinese firms mainly sell to their own market and thus they do not currently have to worry about the weakness of their brand in foreign markets. Furthermore, Chinese firms to not mainly compete on their ability to produce discrete products, but on their ability to install networks and communications systems that comprise several pieces of equipment ('total solutions'). Therefore it is not clear that these firms would necessarily be concerned with the types of sales channels that are more relevant to consumer goods and which form the basis of

[7] *Figure 4.2* describes the phenomenon by which the time lag between initial product introduction by foreign companies and indigenous production is shortening.
[8] This differs to handset production which falls under consumer electronics.
[9] See *Chapter 3*.
[10] The Chinese government played an important role in consolidating the initially large domestic SPC switching industry given that many producers had inefficiently small plant sizes. This large proliferation was encouraged by the low barriers to entry (the technology was licensed without much restriction by the pioneering domestic companies).

many OEM/ODM contracts for latecomers[11]. However, OEM contracting may still be an opportunity for them as a valuable source of revenues.

Nevertheless, signaling *is* important to domestic companies. Instead of mainly resting upon their production capabilities, it mostly relates to their (potential) market share and their technological capabilities. It is also not directed at customers, but directed to *suppliers*. Suppliers typically want to sell to customers who are strong players in the market. In particular, smaller high-tech suppliers with limited production capabilities want to enter into contracts with customers who will guarantee a source of business and cash flow for their companies. As described in *Chapter 3*, high tech components in this industry undergo shortages and therefore Chinese firms must compete with larger established players for the attention of suppliers in order to not get cut off from their sources of critical components. An important way in which companies display their 'worthiness' is by showing a potential to become major players in the market. The fact that the Chinese market is so large and that the Chinese government will back domestic firms in capturing market share is one factor that can attract suppliers. However, what differentiates domestic companies from one another as 'better customers' are their respective technological capabilities. These indicate greater potential both at home and abroad.

Lastly, it is not clear to what extent economies of scope come into play with companies such as Huawei and ZTE. Amsden and Chu describe how scope was important with Taiwanese firms in the IT sector which used the skill of integration to spread fixed costs of design and prototyping among different customers. In the case of the telecom infrastructure equipment industry, different categories of communications equipment (e.g. optical, networking and cellular) are radically different from each other in design and technology. This limits the potential economies of scope in design.

Project Execution Skills

Project execution skills have been very important for the domestic firms studied. Both Huawei and ZTE, have employed professional staff at the highest levels of the company. This may have been expected for ZTE, given that it is a state-owned company, however even Huawei – a private firm – is not under family control but has a hierarchical structure of professional management. Nevertheless, corporate governance may be an issue for other state-owned domestic companies in the industry, for example Julong. Although top managers may be professionals, the real strategic decision-makers may not be managers within the company but instead are appointed officials. There is no doubt that effective project execution has been essential to the remarkable organic growth undergone by these companies and their expansion into various areas of communications technology. This relates to the characteristic of many latecomers which have tended to diversify into unrelated lines of business – project execution skills gained in one area being applied to other areas (for example, the growth of Korean *chaebols*). However, domestic firms in the industry studied have tended to remain within the same broad business of

[11] For example, the subcontracting by major PC brands of notebook and desktop manufacturing to Taiwanese firms.

communications equipment, although they are diversified within this area. This may be due to the fact that the sector is profitable enough to sustain a focus in the industry, or may be due to government policy pressures.

Although project execution skills in one area may have been used by domestic firms to spearhead diversification into another area of communications equipment, technological capabilities have generally been the limiting factor. Products developed by Huawei and ZTE have not been defined by the usual characteristics of maturity which are that the technology is relatively available through subcontracting and technology transfer agreements. Thus the pace of diversification of the Chinese companies considered here has usually depended upon the pace of their reverse-engineering and R&D efforts (having not engaged in joint production JVs with foreign companies). Therefore the management of 'R&D' processes, as opposed to mainly production processes, has been one of the biggest concerns of these firms.

Ramping up

In light of the fact that scale economies do not seem to be as important in this industry as in other fields of electronics and IT, the fast ramping up of production is probably not so much of a focus for the firms studied. The first 'ramping up' that needs to occur is in the product development process. After a promising market or technology trend is identified, the domestic firms have had to devote considerable efforts in undertaking preliminary studies, putting together a team of suitable engineers, expanding the team and often moving it to dedicated R&D centers. Because of the enormous front-end effort of self-development (as opposed to technology acquisition through technology transfer), production ramping up takes second place.

Furthermore, in some cases it seems that technologies have not been entirely de-bugged. For instance, certain microchips provided for Huawei's Internet routers by foreign suppliers necessitated some lengthy de-bugging by the suppliers' engineers because the components were new on the market. This adds weight to the argument that equipment produced by the firms studied does not entirely fit the definition of 'mature products', and thus does not confer the advantages enjoyed by second movers in other industries.

Globalization and Nationalization

This part of the second mover advantage theory postulates that second movers arise from the changes in industrial structure caused by product maturation. That is, a movement from foreign direct investment (FDI – designed to protect proprietary foreign technology) to foreign indirect investment and subcontracting on an OEM or ODM basis (when products are mature or patents have run out).

In the case of the telecom infrastructure equipment industry in China, the most important manufacturers today have not emerged from joint ventures (FDI), nor do they seem to be heavily involved in subcontracting arrangements with foreign companies, even for mature products such as switching equipment. Several reasons may account for this.

Firstly, the size of the home market is large enough to support production that is not based on subcontracting for foreign companies. Secondly, in cases where Chinese firms are beginning to sell abroad, they are aiming for cost-sensitive developing country markets where they are able to successfully compete on price against foreign manufacturers. Thus they do not have a need for subcontracting arrangements given that they are able to market themselves independently.

Conclusions

The above discussion suggests that second mover advantage theory does not apply wholesale to firms such as Huawei and ZTE. It seems that these companies need to compete under a somewhat different set of paradigms than firms in other electronics and IT industries. This is accounted for by the fact that, although products may be relatively mature, firms still need to invest significant resources in reverse engineering and R&D capabilities to acquire the technology. Furthermore, the type of market in which they compete does not necessarily dictate an upward shift in scale economies when products mature.

Appendix 1: List of Interviewees

Telecom Companies (Chinese)

1. Marketing Supervisor, ZTE Corp.
2. International Marketing Representative, ZTE Corp.
3. Vice-Director, Shanghai Research Institute I, ZTE Corp.
4. Engineer, Beijing Research Institute, ZTE Corp.
5. Mobile Business Manager, ZTE Corp.
6. Chief Manager, Beijing Research Institute, Huawei Technologies.
7. Engineer, Beijing Research Institute, Huawei Technologies.
8. Senior Engineer, PTIC Information Industry Corporation.
9. North China Market Director, Sales Division, Beijing International Switching System Corporation (BISC).

Telecom Companies (Foreign)

10. Senior Manager, Government Relations & Strategic Development, Nortel Networks.
11. Senior Specialist, Strategic Development, Nortel Networks.
12. Managing Director, Product Marketing Development, Optical Networking Group, Lucent Technologies.
13. Sales Manager, Extreme Networks.
14. Assistant Sales Manager, Mobile Products, Siemens.

Academic Institutions

15. Executive Dean of the Graduate School, Professor of Management Science and Information Management.
16. Assistant Professor, School of Economics and Management, Qinghua University.

Chinese Government

17. Chief, State Information Center, Ministry of Information Industry.
18. Senior Engineer, Ministry of Information Industry.
19. Chief Engineer, Ministry of Information Industry.

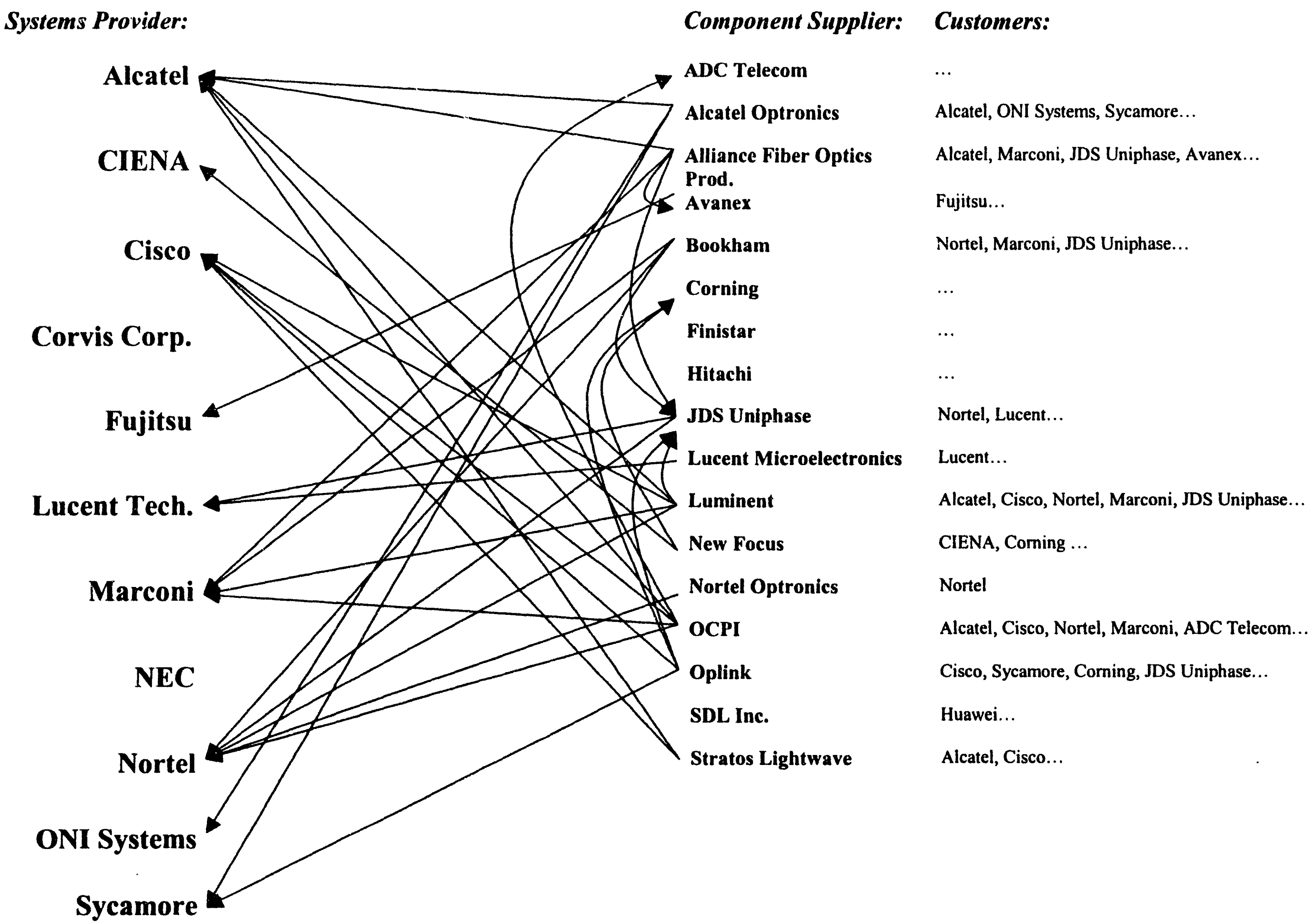
Consultancies and Market Analyst Firms

20. Managing Director, BDA (Beijing).
21. Chief Telecom Analyst, Frost & Sullivan (Beijing).
22. Consultant, McKinsey & Co. (Beijing).

Appendix 2: International Perspective on the Telecom Equipment Industry

- *Appendix 2A: Network of Relationships Between Component Suppliers and Systems Producers*
- *Appendix 2B: Selected Privately-owned Companies*

APPENDIX 2A INTERNATIONAL OPTICAL EQUIPMENT INDUSTRY NETWORK (SELECTED RELATIONSHIPS)



Source: Based on information from Merrill Lynch (2000) and MSDW (2000)

Notes on Appendix 2a

- The information above is not complete as not all relationships between component suppliers and their customers have been shown.
- Only publicly-traded component suppliers have been included above.
- Several component companies directly supply certain service providers and infrastructure suppliers, in addition to the systems providers.
- JDS Uniphase outsources some manufacturing to Celestica.
- OCPI is 69.3% owned subsidiary of Furukawa.
- Stratos is 84% owned by Methode.

Appendix 2B Selected Privately-Owned Companies

Optical Systems Providers

These are a selection of new entrants in the optical systems markets, each of which offers different types of products[1].

- Alidian Networks
- Appian Communications
- Astral Point
- Atoga Systems
- Atrica
- Brightlink (Corvia)
- Calient Networks
- Celox
- Centerpoint Broadband Technologies
- Coriolis
- Geyser Networks
- Innovance Networks
- Kestrel Solutions
- Latus Networks
- Laurel Networks
- Lightscape Networks
- Mayan Networks
- Metro-Optix
- Native Networks
- OptiMight
- PhotonEx
- Tellium
- Teraburst
- Tropic Networks
- Village Networks
- White Rock Networks
- Xtera
- Zaffire

[1] Source: Merrill Lynch (2001)

Optical Component Suppliers

These are a selection of small, private companies which hold numerous cutting edge and potentially 'disruptive' technologies[2]:

- Agility Communications
- Bandwidth9
- Blaze Network Products
- Chorum
- CiDra
- IPG Photonics
- ITF Optical Technologies
- Kymata
- LightLogic
- Lightwave Microsystems
- OMM
- Onyx Microsystems
- Southampton Photonics
- SpectraSwitch
- Teem Photonics
- TeraXion
- Wavesplitter Technologies
- Zenastra Photonics

[2] Source: Merrill Lynch (2000), and Morgan Stanley Dean Witter (2000).

Appendix 3: List of Chinese Companies and Foreign Joint Ventures in the Telecom Infrastructure Equipment Industry

APPENDIX 3A CHINA PTIC INFORMATION INDUSTRY CORPORATION

Wholly-Owned Factories

PTIC Houma Communications Cable Factory	
Main Products:	Optical Cable Cable
Location:	Houma, Shanxi

PTIC Xi'an Communications Equipment Factory	
Main Products:	Digital Microwave Wireless frequency amplifier Microwave antenna Mobile Station Antenna
Location:	Xi'an

Chengdu P&T Communications Equipment Factory	
Main Products:	No. 7 signal monitor DWDM MDF Amplitude Moderation CATV transmitter and receiver
Location:	Meishan, Sichuan

Beijing P&T Communications Equipment Factory	
Main Products:	GSM system and handset Digital Microwave
Location:	Beijing

PTIC Beijing Telecommunications Equipment Factory	
Main Products:	Power supply MDF Telephone set, plugs
Location:	Beijing

PTIC Tianjin Communications Equipment Factory	
Main Products:	Postal bag, electric tourist vehicle, accumulator tractor, transportation system for the letterbox.
Location:	Tianjin

Tianjin Telephone Equipment Factory	
Main Products:	Magcard, Magcard Telephone set and management system IC Card, IC Card phone and system
Location:	Tianjin

Shanghai Telephone Equipment Factory	
Main Products:	Digital subscriber switch
	Power supply for the intelligent high frequency switch,
	Video doorbell phone system
	Semiconductor discharger
	Coin telephone set
	Cordless phone, incoming phone
Location:	Shanghai

PTIC Jingdezhen Communications Equipment Factory	
Main Products:	Fixed wireless access equipment
	MDF
	Centralized surveillance system
	Intelligent traffic signal machine
Location:	Jingdezhen, Jiangxi

PTIC Guiyang Communications Equipment Factory	
Main Products:	Telephone sets
	MDF
	Public telephone booths
Location:	Guiyang

PTIC Zhuzhou Communications Equipment Factory	
Main Products:	Modularized Lightening proof for the communication power lines
Location:	Zhuzhou, Hunan

PTIC Ji'nan Communications Equipment Factory	
Main Products:	Postal container, postal vehicle
Location:	Zhangqiu, Shandong

PTIC Guilin Telecommunications Equipment Factory	
Main Products:	Fax machine, franking machine
	Microwave equipment
	Switch power supply
	Electrical networking equipment
Location:	Guilin

PTIC Luoyang Huanghe Motorcycle Factory	
Main Products:	Motorcycles
Location:	Yanshi, Henan

PTIC Guiyang Communications Machinery Factory	
Main Products:	High-speed sorting machine
Location:	Guiyang, Guizhou

PTIC Guilin Communications Equipment Factory	
Main Products:	GSM short message service system
	Large Capacity Voice mail
Location:	Guilin

Holding Companies

Great Dragon Information Technology Co., Ltd.	
Main Products:	HJD04 SPC digital exchange IC card phone and system
Location:	

Shanghai Posts and Telecommunications Equipment Co., Ltd.	
Main Products:	Optic-transmission equipment AFC system Voucher printer Cash register POS system
Location:	Shanghai

Chengdu Cable Co., Ltd.	
Main Products:	Optic Fiber, Optical Cable, cable
Location:	Hi-tech Development Zone, Chengdu

Zhejian Eastcom Communications Co., Ltd.	
Main Products:	GSM mobile communications system equipment & handsets SIM cards Pagers ATM Wireless Optic Access Network
Location:	Hangzhou, Zhejiang

Nanjing P&T Equipment Co., Ltd.	
Main Products:	Data communications products (CDPD, POS, ISDN adapter, desktop video conference) MDF SCDMA wireless access system, Computers Intergate wiring system
Location:	Nanjing, Jiangsu

Chongqing Communications Equipment Co., Ltd.	
Main Products:	PDH products Optic transmission equipment
Location:	Chongqing

Guangzhou P&T Equipment Co., Ltd.	
Main Products:	IC Card public payphones and management systems Optic transmission systems MDX200 Integrated Access Network System
Location:	Tianhequ, Guangzhou

Wuhan Zhouji Telecom Power Supply Group Co. Ltd	
Main Products:	Centralized Monitor and control system for telecom power Power room and air-conditioning Low voltage variable switchgear assemblies Sealed batteries
Location:	Wuhan

Hangzhou Hongyan Electrical Appliances Co., Ltd.	
Main Products:	Various types of new plugs Integrated wireless systems Intelligent Building systems
Location:	Hangzhou, Zhejiang

Beijing Matsushita Communications Equipment Co., Ltd.	
Main Products:	GSM handsets and systems Pagers
Location:	Tianzhu East Road Beijing Airport Industrial Development, Beijing

Shanghai Radio Communications Equipment Manufacturing Co., Ltd.	
Main Products:	IP Switching systems Hi-flex systems Intelligent dialers
Location:	Pudong, Shanghai

Shenzhen Lingyun Electronics Co., Ltd.	
Main Products:	Telephones, Portable MP3
Location:	Bao'an District, Shenzhen

Zhuhai Peace Telecommunications Industry Company	
Main Products:	SIM cards, pagers, handset batteries
Location:	Zhuhai, Guangdong

'Full Ownership' Enterprises and Affiliated Units

Centel Telecommunications Co., Ltd.	
Main Products:	Network management, billing, and supervision and testing systems for mobile, local and No. 7 signal networks Access routers ISDN terminals Internet information technology service systems
Location:	Xicheng District, Beijing

Beijing Taili Technology Development Company	
Main Products:	Mobile communications equipment
Location:	Beijing

PTIC Peace Communications Technologies Company	
Main Products:	114 national telephone number query system Internet file information management system Integrated EMS postal management system Network call center platform
Location:	Xicheng District, Beijing

Beijing Optical Communications Technology Co., Ltd.	
Main Products:	SDH optical fiber transmission system, SDH access network Online testing system Local integrated transmission network management system
Location:	Xicheng District, Beijing

PTIC R&D Center	
Main Products:	IPA enterprise-level gateway system IPB telecom-level gateway system V5 gateway system Mini-PBX
Location:	Beijing

Further Affiliated Companies and Units (products produced not specified):

- **PTIC Beijing Company** (Beijing)
- **PTIC Hangzhou Company** (Hangzhou)
- **PTIC Guangzhou Company** (Guangzhou)
- **PTIC Xiamen Company** (Xiamen)
- **PTIC Shanghai Company** (Shanghai)
- **PTIC Shanghai Telephone Equipment Company** (Shanghai)
- **PTIC Wuhan Company** (Wuhan)
- **PTIC Changchun Company** (Changchun)
- **PTIC Zhengzhou Company** (Zhengzhou)
- **PTIC Tianjin Company** (Hedongqu, Tianjin)
- **PTIC Xi'an Company** (Xi'an)
- **PTIC Chengdu Company** (Chengdu)
- **PTIC Guilin Company** (Guilin)
- **PTIC Nanjing Company** (Nanjing)
- **PTIC Harbin Company** (Nangang District, Harbin)
- **PTIC Designing and Planning Institute for Engineering** (Beijing)
- **Research Institute for Telecom Standardization** (Beijing)
- **PTIC Training Center** (Beijing)
- **China Communication Industry Paper** (Yuzhongqu, Chongqing)

Joint Ventures (Mutual Shareholding Companies)

Beijing Ericsson Mobile Communications Co., Ltd.	
Main Products:	GSM handsets and systems
Location:	Industry Development Zone, Tianzhu Airport, Shunyi, Beijing

Lucent Technologies Shanghai Optical Fiber Co., Ltd.	
Main Products:	DACSH, SDH Transmission Equipment Access Network Equipment
Location:	Shanghai

Shanghai Shindengen Communications Equipment Co., Ltd.	
Main Products:	High-frequency switch power supply
Location:	Shanghai

Beijing Haihong Communications Systems Co., Ltd.	
Main Products:	Postal saving computer network
Location:	Haidan District, Beijing

Shandong Huari Battery Co., Ltd.	
Main Products:	Closeed Storage Batteries of varied capacity
Location:	Zhangqiu, Shandong

Beijing Hongna Postal Articles Co., Ltd.	
Main Products:	Philately articles
Location:	Fengtai District, Beijing

Hangzhou Motorola Cellular Equipment Co., Ltd.	
Main Products:	CDMA system equipment
Location:	Economic and Technological Development Zone, Hangzhou, Zhejiang

Hangzhou Eastcom Cellular Phone Co., Ltd.	
Main Products:	GSM, CDMA handsets
Location:	Economic and Technological Development Zone, Hangzhou, Zhejiang

Lucent Technologies Beijing Optical Cable Co., Ltd.	
Main Products:	Optical cable
Location:	Economic and Technological Development Zone, Beijing

Beijing Changxinjia Information Technology Co., Ltd.	
Main Products:	Network audio player, digital cameras, wireless sound box
Location:	Haidan district, Beijing.

APPENDIX 3B FUJITSU

Fujitsu (China) Co., Ltd. Established in 1995. Promotes business activities in China, including partnerships with local investments and staff training.
Representative Offices: Beijing, Shanghai, Guangzhou, Xi'an.

Joint Ventures

Shanghai Fujitsu Telecommunications Equipment	
Main Products:	FETEX-150 printed circuit boards and other switch components
Ownership:	Fujitsu (68%); Shanghai First Telecom Equipment Plant (32%)
Staff:	110
Location:	Shanghai

North China Fujitsu Telecommunications Equipment Co., Ltd.	
Main Products:	Responsible for sales, maintenance and technical support of ATM switches and other systems for LAN/WAN network.
Ownership:	Fujitsu (China) (49%); Hebei Far East Communication System Engineering Corp. (51%)
Staff:	39
Location:	Shijiazhuang, Hebei

Jiangsu Fujitsu Telecommunications Technology Co., Ltd.	
Main Products:	FETEX 150 systems
Ownership:	Fujitsu and partner Nissho Iwai (55%); Jiangsu PTA and Suzhou Electrical Machinery Factory (45%)
Staff:	570
Location:	Jiangsu

Fujian Fujitsu Communications Software Ltd.	
Main Products:	Software for its local FETEX equipment
Ownership:	Fujitsu (49%)
Staff:	190
Location:	Fujian

Nanjing Fujitsu Telecommunications Equipment Co. Ltd.	
Main Products:	SDH/PDH fibre-optic transmission systems
Ownership:	Fujitsu (40%); Nanjing Telecommunications Factory (60%)
Staff:	300
Location:	Nanjing

Notes: In 1998, sales at Najing Fujitsu totaled $36.7m (a 77% increase from 1996 sales). Similarly, its staff figures have also climed from 163 in 1996 to 300 in 1999.

Xi'an Fujitsu Telecommunications Equipment Co. Ltd.	
Main Products:	Radio and mobile communication systems
Ownership:	Fujitsu (60%); Xi'an Telecommunications Equipment Co. Ltd.
Staff:	n/a
Location:	n/a

APPENDIX 3C LUCENT TECHNOLOGIES

Wholly-Owned Companies (check: should be only TWO)

Lucent Technologies Qingdao Telecommunications Equipment Co. Ltd.	
Main Products:	5ESS-2000 public switching equipment
Staff:	Over 800, mostly in engineering or management positions
Location:	Qingdao

Note: This is Lucent's largest switching equipment production plant outside the US.

Lucent Technologies of Shanghai	
Main Products:	Optical digital transmission systems, including SDH
Location:	Shanghai

Lucent Technologies of Tianjin Cable Co. Ltd.	
Main Products:	Cable products
Location:	Tianjin

Lucent Technologies Beijing Fiber-Optic Cable Co. Ltd.	
Main Products:	Fiber-optic cable
Location:	Beijing

Note: This has become Lucent's largest production facility outside the US for fiber-optic cable.

Joint Ventures

Lucent Technologies Shanghai Fiber Optic Co. Ltd.	
Main Products:	Fiber optic products
Ownership:	Lucent (56%); Shanghai Optical Communications Development (20%)
Location:	Shanghai

Guoxin Lucent Technologies Network Co. Ltd.	
Main Products:	Specializes in R&D of network management and technology consulting services
Ownership:	Lucent, China Telecom and Shanghai PTB
Location:	Shanghai

Lucent Information and Communications of Shanghai	
Main Products:	Software
Ownership:	Lucent, Shanghai PTA
Location:	Shanghai

R&D Facilities

Bell Labs & Peking University	
Main Products:	Software technologies
Location:	Beijing

Bell Labs & Shanghai Jiaotong University	
Main Products:	Communications and network development
Location:	Shanghai

APPENDIX 3D NEC

Joint Ventures

Tianjin NEC Electronic & Communications Industries	
Main Products:	n/a
Ownership:	Tianjin NEC Electronic & Communications Industries (25%); Tianjin PTA and NEC affiliate Sumitomo Shoji Kaisha
Location:	Tianjin

Wuhan NEC Fiber-Optic Communications Industry Co.	
Main Products:	SDH/PDH fiber-optic transmission systems
Ownership:	NEC (35%); Chanjiang Fiber Optic Industry Group (51%); Sumitomo Shojo Kaisha (14%)
Location:	Wuhan

Xi'an NEC Radio Communications Equipment Co. Ltd.	
Main Products:	SDH based large-capacity microwave communications systems
Ownership:	NEC (41%); NEC China (19%); No. 4 Research Institute of the MII (40%)
Location:	Xi'an

Beijing Telecommunications Equipment Factory	
Main Products:	NEC-500 DMW radios
Ownership:	NEC; Beijing Telecommunications Equipment Factory
Location:	Beijing

Guilin NEC Radio Communications Ltd.	
Main Products:	SDH based microwave systems Digital local access systems/wireless local loop
Ownership:	NEC (60%); Lijiang Radio Factory (40%)
Location:	Guilin

APPENDIX 3E NORTEL NETWORKS

Joint Ventures

Guangdong-Nortel Telecommunications Switching Equipment Ltd.	
Main Products:	DMS Super Mode products, digital access, multimedia data systems (including CDMA equipment).
Ownership:	Nortel (62%); China National Hua Xin PTA Bureau, Hebei PTA, Henan PTA, China International Telecommunications Construction Corp., and Guangdong Macro Group Corp.
Staff:	800
Location:	Guangdong

Tongguang Nortel Ltd.	
Main Products:	Meridian 1 communications sytem
Ownership:	Nortel; Tongguang Electronics Co.
Staff:	400
Location:	Shenzhen

Shenyang Nortel Telecommunications Co. Ltd.	
Main Products:	SDH transmission systems
Ownership:	n/a
Staff:	75
Location:	Shenyang

Shanghai Nortel Semiconductor Corp.	
Main Products:	Design and supply of integrated circuits
Ownership:	n/a
Staff:	45
Location:	Shanghai

Advanced Semiconductor Manufacturing Corp. of Shanghai	
Main Products:	Integrated circuit wafer foundry
Ownership:	n/a
Staff:	450
Location:	Shanghai

R&D Facilities

Guangdong Nortel and Guangzhou's Zhongshan University	
Main Products:	DMS
Location:	Guangdong

Guangdong Nortel (Shunde)	
Main Products:	DMS core development
Location:	Guangdong

Beijing University of Posts and Telecommunications – Bell Northern Research	
Main Products:	Advanced wireless and networking technology
Location:	Beijing

APPENDIX 3F SIEMENS

Siemens Business Communications Systems Ltd. (SBCS)	
Main Products:	Hicom 300E and Hicom 100 digital telephones and desktop telecommunications products Application products and services such as PhoneMail product line, ISDN applications networking, PBX/computer applications, automatic call detail recording. Broadband application product of Hicom ACCS, and solution of ISDN network to ATM.
Ownership:	n/a
Location:	n/a

Siemens Shanghai Mobile Communications	
Main Products:	Sets of GSM mobile equipment, including base station systems and mobile terminals.
Ownership:	Siemens (60%); Shanghai PTA, Shanghai Audio & Visual Co. and No. 1 Institute of the MII.
Location:	Shanghai

Note: Adapted BISC's EWSD switches for cellular applications.

Siemens Shanghai Communications Terminals Ltd.	
Main Products:	Wire, wireless and cordless telephones
Ownership:	Siemens Corp.; Shanghai Guangdian Co. Ltd.
Location:	Shanghai

Beijing International Switching System Corp. (BISC)	
Main Products:	EWSD switches and mobile switching centers
Ownership:	Siemens (40%); Beijing PTA (2.73%); Beijing Enterprise Ltd. (40%); Beijing Wire Communications Plant (8.6%); Beijing Comprehensive Investment Co. (8.67%)
Staff:	1,500
Location:	Beijing

Siemens Communications Systems Ltd.	
Main Products:	"Last mile" products for telecommunications networks with focus on systems using fiber-optic and radio technology
Ownership:	Siemens (50%); Chengdu Posts and Telecommunications Equipment Factory; Chengdu Telecommunications Cable Co. Ltd.
Staff:	700
Location:	Sichuan

Siemens Optical Fiber Cable Ltd.	
Main Products:	Entire range of fiber-optical cables, including terrestrial and fiber ribbon cables.
Ownership:	JV with local cable company in Chengdu
Location:	Chengdu

Siemens Telecom Power Supply Ltd.	
Main Products:	Siemens GR60 telecom power supply and Siemens UPS
Ownership:	n/a
Location:	Shanghai

Guangzhou Nanfang Transmission Systems	
Main Products:	PDH and SDH fiber-optic transmission systems
Ownership:	Siemens (40%); Guangdong PTB and Nanfang Factory (60%)
Location:	Guangzhou

Appendix 3G Ericsson

Joint Ventures

Beijing Ericsson Communications Systems	
Main Products:	MD110 PBX and AXE local and mobile exchanges
Ownership:	Ericsson (40%); Beijing Wire Communication Plant (60%)
Location:	Beijing

Note: 20% of transmissions systems sold in 1998 were manufactured by this joint venture (the rest was imported).

Beijing Ericsson Mobile Communications	
Main Products:	GSM/TACS base stations, handsets, mobile network design and implementation
Ownership:	Ericsson; Radio Factory No. 506; Radio Factory No. 508
Location:	Beijing

Dalian Ericsson Communications	
Main Products:	CO switch and cellular system support for N.E. China
Location:	Dalian

Nanjing Ericsson Communications	
Main Products:	Switching/cellular system support, transmission equipment
Ownership:	Ericsson; Panda Group; Nanjing Radio Factory
Location:	Nanjing

Note: Approximately 70% of hardware components for Ericsson's AXE 10 switches sold in China are produced by this joint venture, as well as from its Beijing joint ventures.

Shanghai Ericsson Simtek Electronics	
Main Products:	Complete Line Interface Circuits
Location:	Shanghai

Wuhan Yangtze Ericsson	
Main Products:	SDH equipment
Location:	Wuhan

Guangzhou Ericsson Co.	
Main Products:	RBS and channeling equipment
Ownership:	Ericsson; Guangdong PTA, Guangdong Radio Factory
Location:	Guangzhou, Guangdong

Guangdong Ericsson Mobile Communications Co.	
Main Products:	Provides GSM and TACS infrastructure engineering services
Ownership:	Ericsson; Guangdong PTA
Location:	Guangzhou, Guangdong

Note: Ericsson and the Wuhan Research Institute established a joint venture in 1999 for transmission equipment production. It will mostly be using imported kits and will initially not be locally sourcing components.

R&D Facilities

LME R&D Center	
Main Products:	Develop solutions for data and telecoms with a focus on network access software
Location:	Shanghai

Note: This R&D center cooperates with the Wuhan Research Institute, Beijing University of Posts and Telecommunications, Beijing Institute of Technology, and Beijing Design Institute.

Appendix 3H Alcatel

Alcatel has 20 telecom equipment manufacturing companies in 11 cities in China covering switching, microwave transmission systems, optical fiber lines, fixed wire and wireless access systems and mobile infrastructure equipment.

Joint Ventures

Alcatel Shenyang Telecommunication Co., Ltd.	
Main Products:	Wire and wireless phones
Ownership:	Hong Kong Alcatel (China) Co. Ltd; Shenyang Telecom Bureau;
Location:	Shenyang

Fujian Alcatel Communications Technology Co. Ltd.	
Main Products:	Wire and wireless phones
Ownership:	Alcatel (China) Co. Ltd.; Fujian Bamin Telecom Ltd.
Location:	Fujian

Shanghai Bell Telephone Equipment Manufacturing Co. (Shanghai Bell)	
Main Products:	S12 switches
Ownership:	Alcatel (32%); MII-Huaxin (60%); Belgian Government (8%)
Location:	Shanghai

Shanghai Bell – Alcatel Mobile Communications	
Main Products:	GSM base stations, control equipment, mobile switches, digital handsets
Ownership:	Alcatel ; Shanghai Bell
Location:	Shanghai

Shanghai Belling	
Main Products:	Custom CLSI chips for S12 switches, ISDN, ADSL and ISM equipment
Ownership:	Shanghai Bell; Shanghai Radio Factory No. 4
Location:	Shanghai

Alcatel (Chengdu) Communications Systems Co.	
Main Products:	PDH/SDH fiber-optic transmission systems
Ownership:	Alcatel; Meisheng Telecommunications Equipment Factory
Location:	Chengdu

Alcatel Chongqing	
Main Products:	DMW technology with Alcatel Telettra for 1.5 GHz systems
Ownership:	Alcatel Telettra and MII Factory No. 716 (ex-MEI)
Location:	Chongqing

Alcatel (Beijing) Transmission System Co. Ltd.	
Main Products:	Small, medium and high-capacity DMW systems, including STM-1 SDH microwave
Ownership:	Alcatel (50%); PTIC Factory No. 506 (50%)
Location:	Beijing

Tianjin Alcatel Electromagnetic Wires and Cables Ltd.	
Main Products:	Copper wire and cables for electrical coils
Ownership:	Alcatel (60%); Tianjin Electromagnetic Wire Factory (40%)
Location:	Tianjin

APPENDIX 3I NOKIA

Wholly-Owned Companies

Nokia (Suzhou) Telecommunications Co.	
Main Products:	GSM base stations and cellular network transmission products
Location:	Suzhou, Jiangsu

Joint Ventures (Mobile Communications)

Beijing Nokia Hang Xing Telecommunications Co.	
Main Products:	Mobile digital switching centers, base station controllers and fixed digital switches
Ownership:	Nokia; Hang Xing Manufacturing Co.
Location:	Beijing

Beijing Nokia Mobile Telecommunications Ltd.	
Main Products:	GSM digital cellular systems and mobile phones
Ownership:	Nokia; Beijing Telecommunications Equipment Factory
Location:	Beijing

Dongguan Nokia Mobile Phones Co.	
Main Products:	Mobile phones and accessories
Ownership:	Nokia; Dongguan Telecommunications Development General Co.
Location:	Guangdong

Fujian Nokia Mobile Communications Technology Co.	
Main Products:	GSM 900/1800 technical services
Ownership:	Nokia; Fujian PTA
Location:	Fujian

Chongqing Nokia Telecommunications	
Main Products:	Fixed network products
Location:	Chongqing

APPENDIX 3J MOTOROLA

Joint Ventures (Mobile Communications)

Shanghai Motorola Paging Products	
Main Products:	FLEX pagers
Ownership:	Motorola; Shanghai Radio Communications Equipment Manufacturing Co. Ltd.
Location:	Shanghai

Hangzhou Motorola Cellular Systems Ltd.	
Main Products:	CDMA digital cellular infrastructure equipment and services
Ownership:	Motorola; China National Posts & Telecommunications Industrial Corp; Eastcom
Location:	Hangzhou, Zhejiang

Hangzhou Motorola Cellular Phone Ltd.	
Main Products:	GSM infrastructure equipment
Ownership:	Motorola; Eastcom; Zhejian Technical Import-Export Corp (ZTIEC)
Location:	Zhejiang

Note: under this agreement, Eastcom can make and distribute Motorola's latest GSM cell site equipment to cellular operators in China, and distribute all of Motorola's GSM base station equipment.

n/a = information not available

Appendix 4: Selected Chinese Government Policy Statements

Partial summary of comments by Wang Jianzhou, former Director-General of the MII's integrated planning department, made at a coordination meeting held in Beijing (November 1998), outlining current and future strategies[1]:

- Investment in research will be increased to develop Chinese telecommunications products, so that China will become less dependent on imported technology;
- Chinese telecom operators should give priority to domestic products when the price and quality are similar to imported products;
- Chinese-foreign joint ventures are expected to speed up technology transfer to their Chinese partners, increase the proportion of locally sourced raw materials and develop new products to meet market demand;
- China will actively participate in the process of developing IMT-2000, the third generation CDMA standard.

Summary of the *Circular regarding the strengthening of supervision and control, to promote the healthy development of the mobile telecommunications production industry*, distributed by the State Council (1998)[2]:

- The value-added of production in China's infant industry is low, and technology transfer is low. China must improve its domestic management and production.
- China should avoid construction duplication. Therefore, provinces and ministries cannot approve joint ventures or wholly-owned foreign enterprises that product GSM systems, unless the equipment is to be exported. GSM negotiations underway should be stopped, and any contracts recently signed should not be executed. GSM imports must be "controlled".
- Permits allowing network access and contract signings must be "controlled". GSM production enterprises should be more closely supervised to ensure technology transfer, higher export-to-domestic sales ratios and a larger percentage of locally sourced inputs. Customs shall crack down on smuggled equipment, especially handsets.
- China should support domestic industry with Chinese intellectual property. 5% of installation fees (1998-2000) will be dedicated to support mobile telecommunications research. Bonds should be issued to assist in R&D efforts. Research priority should be given to mobile telecom equipment with Chinese intellectual property.

[1] Pyramid Research (1999b)
[2] Pyramid Research (1999b)

- China should choose and support three to five state-level mobile communications R&D centers, and encourage R&D centers overseas to obtain technology. Personnel and funds should move smoothly overseas to support these centers.
- The Ministry of Science & Technology and the MII should work together on the research and development of the third generation (3G) mobile communications system (IMT-2000), and actively work with the international telecommunications union in setting technical standards for 3G mobile telecommunications.

Partial summary of an MII implementation proposal, *Implementation plan to speed up the development of China's mobile telecommunications industry*, (1998):

- Shanghai Bell and Alcatel is the only JV that has a high level of technology transfer. Datang is the only company that can currently produce mobile exchanges and base stations. Mobile systems produced by Huawei, Zhongxing, Jinpeng and Julong are preparing for tests in these areas.
- The main problems confronting the entirely Chinese manufacturers include inadequate investment, high risks as they are competing against JVs and WOFEs and foreign patents that can greatly increase production costs.
- Once the products with Chinese intellectual property reach the "network access standard", then a procurement policy of giving priority to these products should be adopted.
- Market Share targets for the mobile industry:

	% market share for domestic goods vendors		% of locally sourced components for JV/WOFE manufacturing in China	
Year	2001	2003	2001	2003
Mobile switches	40%	70%	60%	80%
Base stations	25%	50%	40%	60%
Handsets	10-15%	30%	40%	60%

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