F. Financing Innovation

Financial Sources and Performance of Technological Innovation in China[1]

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This paper systematically studies structure of financial sources and performance of technological innovation in China, which includes three parts with inherent relations. In the first part of this paper we describe the level of economic development and the stage of technological innovation development, analyze comparably the characteristics and changes of finance system and science and technology system. In the second part of this paper we discuss the source structure for financing technological innovation in the last decade, deal with the objectives, functions, scope and change for each financial source in detail, indicate the relations between different sources. Technological innovation performance contributed by different financial source is hard to measure, but we can choose the indicators to present the performance. In the third part of this paper, we consider two indicators: numbers of invention patent and the degree of technology deepening.

Introduction

Funding is one of the most important resources that innovation required. However, funding also is one of the shortest resources for innovation. Whether other countries or China, many surveys discovered that lack of money is one of the top factors to baffle innovation. In China, lack of money ranks the number one in obstacle factors. Just as Gompers and Lerner said in the first sentence of their book "Money of invention: Innovations fail to create value when they cannot attract the resources required to develop them."

Comparing with other topics in technological innovation a few studies on financial sources for technological innovation in China were done. However, more and more money has input into technological innovation process, and both central government and

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local governments and more and more firms consider innovation as the strategic action and a tool of competition. Therefore, financing for technological innovation should be studied and considered profoundly.

This paper examines financial sources of technological innovation in China in three pans. In the first part of this paper we describe the level of economic development and the stage of technological innovation development, analyze comparably the characteristics and changes of finance system and science and technology system. In the second pan of this paper we discuss the source structure for financing technological innovation in the last decade, deal with the objectives, functions, scope and change for each financial source in detail, indicate the relations between different sources. In the third part of this paper, we study the basic relations between performance change of technological innovation and financing for innovation. Numbers of invention patent, sales of new product in percent of total sales and the degree of technology deepening are used as measurement of financial sources contribution to technological innovation. Finally, it is the conclusion of this paper.

Stages of Technological Innovation, Financial System and Science and Technology System

From the point of view of economic development, Chinese GNP ranked sixth in the world and reached above 1 .2 trillion US dollars. Some regions such as Beijing, Shanghai and. Shenzhen have more than 3000 US dollars per capita. Ratio of R&D to GOP in China reached 1% in 2000. According to the theoretical analysis of the stages of technological innovation, China has entered into the period of science and technology takeoff [2] and finished the stage transition from adopting technology to improving technology. Technological innovation becomes much more important in the economic development of China and the core source for firms to acquire competitiveness.

In the view of comparing financial system, China's financial system is the bank-based system. Equity market is less important (Table 1). Capital Market makes less contribution to technological innovation now. Money from bank still is the major source for financing innovation.

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[2] Science and technology takeoff is the period of rapid development of science and technology in a nation, which occurs at the end of the first stage in the technological innovation development.
From studying time serial data of R&D rate of developed countries such as United States, German and France and emerging industrialized countries such as South Koran, we find that R&D rate in the phase of adoption of technology is always lower than 1%. Once the percent is over 1%, the time that R&D rate from 1% to 2% will not take a long time.

Table 1 International comparison of banks and markets (Billions of dollars)

	GDP	Banking assets (BA)	BA/GDP (%)	Equity market Capitalization(EMC)	EMC/GDP (%)
China	1081	1797	166%	581	18(54)?
United States	6301	3319	53	5136	82%
United Kinadom	824	2131	259	1152	140
Japan	4242	6374	150	2999	71
France	1261	1904	151	457	36
Germany	1924	2919	152	464	24

Notes, ? Data in the blanket is the ratio calculated by outstanding stocks. Data outside the blanket is the ratio calculated by the whole stocks including non-outstanding stocks. Data of China is in 2000; other countries data is in 1993.
Sources: Franklin Allen and Douglas Gale, Comparing Financial System, the MIT Press. 2000, p47; China Statistical Yearbook on Science and Technology (2000) and China Statistical Yearbook (2001).

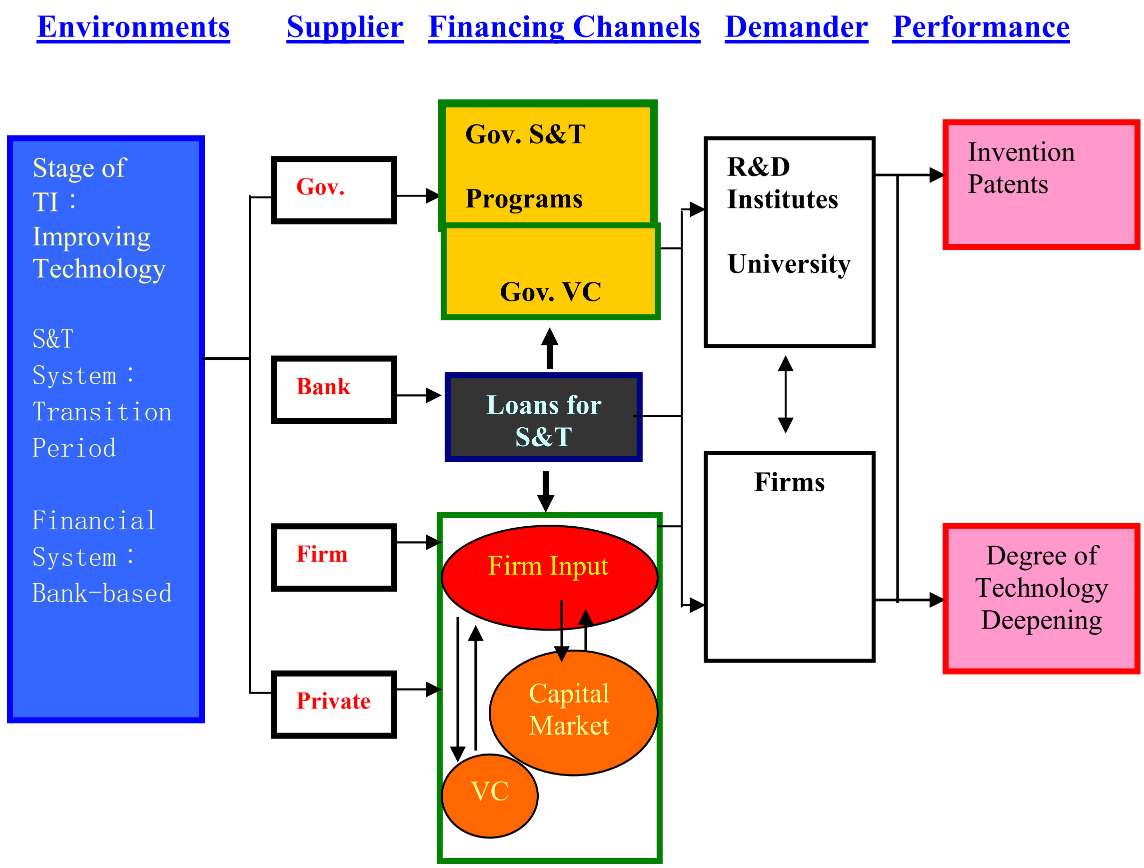
In the view of comparing science and technology system, Chinese science and technology system is in the period of transition both in the macro level and micro level. In the macro level research institutes are reforming, reconstructing and renewal; both central and local governments strengthen and expand science and technology programs, and improve environments of policy. In the micro level firms have the dominant position in the technological innovation. Among firms, research institutes and universities and colleges, firms have the largest inputs in technological innovation.

Sources structure for financing technological innovation

With the development in many years, sources structure for financing technological innovation has been changing in China. Original financing channels still play their roles and new financing channels have been established and developed. As a whole, since 1990s government funds as the percentage of total have raised up and the percentage of bank loan has decreased obviously. However, equity financing, especially internal equity finance has in the dominant position. External equity finance, especially venture capital industry is in its infant stage.

Figure 1 summarizes the fundamental structure of financing technological innovation system. Major financing channels include government direct investment, grant, subsidy and guarantee. Bank loan is the important source of fund for innovation. Through government programs and providing firm the science and technology loan bank indirectly support technological innovation. Government funds used to support technological innovation of firm by various kinds of government program that firm involved. Capital market and venture capital belong to new types of financing channels for technological innovation. Venture capital appears in recent three to four years.

Figure 1 Sources Structure for Financing Technological Innovation (TI)



Science and Technology Program of Government

There are two types of science and technology program of government, which are national mandatory program and national guidance program. National mandatory program includes Climbing Up Program, "883" Program (High-tech Research and Development Program) and Key Projects Program; national guidance program includes Torch Program, Spark Program and Extension Program. In the system of science and technology program of government, there are some other programs[3]. Since only six programs mentioned above have statistical data that can be used, this paper will focus on those six programs.

The fund of national mandatory program mainly inputs into research institutes, which accounts for 45.3% (1999) of total fund. Main financial source of national

[3] Such as Technological Innovation Program, National New Product Project, National Major Science and Technology Industrialization Program, National Key Laboratory.

mandatory program is government fund. Ratio of government fund to non-government fund is about 1:1(actually allocated funds in 1899 are 4.06 billion RMB, of which government funds arranged are 1.9 billion RMB). The fund of national 9uidance program mainly inputs into firm. Percentage of program performed by firm accounts for 91.9%(1999). In the financial sources of national guidance program the ratio of fund from government to bank loans is about 1:10 (actually allocated funds in 1999 werel.38 billion RMB from government fund and 14.1 billion RMB from bank loans).

National mandatory program rolled its hoop in the progress. 81.7% of projects surpassed or reached planned objectives. However, the progress of national guidance program did not satisfy. Only 65.8% of projects surpassed or reached planned objectives. 34.2% of projects did not reach planned objectives. The situation is the closer to the market the higher the percentage of project not reaching planned objectives (Table 2).

Table 2. Projects of National Mandatory and Guidance Program

	National mandatory program			National guidance program		
	Climbing UP	863 Program	Key Projects	Spark	Torch	Extension
Projects surpassed plan	1.7%	6.9%	4.1%	4.5%	5.2%	3.6%
Projects reached plan	96.6%	86.0%	72.8%	62.8%	61.2%	54.8%
Projects did not reach plan	1.7%	7.1%	23.2%	33.6%	32.7%	41.6%

Source: China Statistical Yearbook for Science and Technology (2000)

Science and technology programs of government have achieved significant performance in technology innovation. In 1999 these six programs totally obtained 590 invention patents granted, which account for 19% of total domestic invention patents and 35% of total domestic invention patents in service.

Science and Technology Development Funds

Technological innovation funds of government include funds of central government and local government. Central government fund for technological innovation (Innovation Funds for Technological Small and Medium Firms), founded in 1999, receives 1 billion RMB for each year and supports technological small and medium firms by providing grant, subsidy and equity capital[4]. The purpose to establish innovation fund is to promote technological innovation of firm and accelerate industrialization of achievements of

[4] Grant mainly used in the case that scientist with achievements created a firm and needed an initial fund. In the case that small and medium firms developed new product and done middle test. For the technological innovation projects with certain size and level the subsidy maybe provided in order to support the firm borrowed the money. For the projects with greater innovation and potential demand, equity investment will be adopted Equity investment often does not exceed 20% of registered capital and be required to repay in certain time.

technological science and technology oriented by market, such as industrialization of achievements of "863" Program, Key Projects Program, and "Torch" Program. Its keystone to support is the projects and firms in the early stage of industrialization (seed stage and startup stage) with high growth potential, technology advantage, better market future and the most urgent requirement for the government. At the end of November in 2001, innovation fund has provided about 1.8 billion RMB. Average account of fund for each project is 745,000 RMB. Projects obtained grant account for 75.46%, projects accepted subsidy account for 24.54% [5]. Startup firms less than eighteen months account for 31% of total firms that obtained innovation fund. The projects of R&D and middle test account for 73% of total projects. Innovations fund support concentrated on information technology industry (30%), biology pharmacy industry (18%) and new material industry (15%).

Establishment of national innovation fund brings along the local government's technological innovation funds. Local governments and high technology development zones take three ways to match innovation fund of central government: (1) setting up special funds, that is setting up the similar funds like central government; (2) providing matching money to the projects or firms that got support form innovation fund of central government. For example, Guangdong province decided to setup a fund to provide matching money with the ratio of 3:1 to 1:1; (3) setting up venture capital companies.[6]

Funding from Firms

We should collect several databases to reflect the funds of firm inputted in technological innovation: sources of funds for science and technology; (2) sources of funds for technology development of large and medium-sized firms; and (3) funds for small firm. This is a field that does not be studied yet.

(1) Sources of Funds for Science and Technology.

Before 1992 government funds had been in the dominant position. Since 1992 firm funds has exceeded government fund and located at leading status. And in 1999 the percentage of firm funds to total funds raised up to 35% (Table 3).

[5] Source: www.innofund.gov.cn
[6] Source: www.cssti.net.cn

Table 3 Sources of Funds for Science and Technology (1991-1999) Billion Yuan

	Total	Government Funds	% of Total	Firm Funds	% of Total	Bank Loans	% of Total
1991	43	12.6	29.6%	12.2	28.48%	7.2	16.85%
1992	56	16.0	28.6	16.2	29.15	9.0	16.13
1993	68	17.5	25.96	18.6	27.49	11.9	17.59
1994	79	21.8	27.65	23.4	29.71	12.1	15.40
1995	96	24.9	25.84	30.5	31.71	12.7	13.20
1996	104	27.2	26.07	31.3	29.99	15.0	14.36
1997	118	31.0	26.22	34.8	29.47	15.5	13.13
1998	129	35.3	27.43	40.2	31.21	17.1	13.26
1999	146	47.3	32.38	51.0	34.94	12.9	8.82

Source: China Statistical Yearbook on Science and Technology (2000), China Statistic Press, 2001.

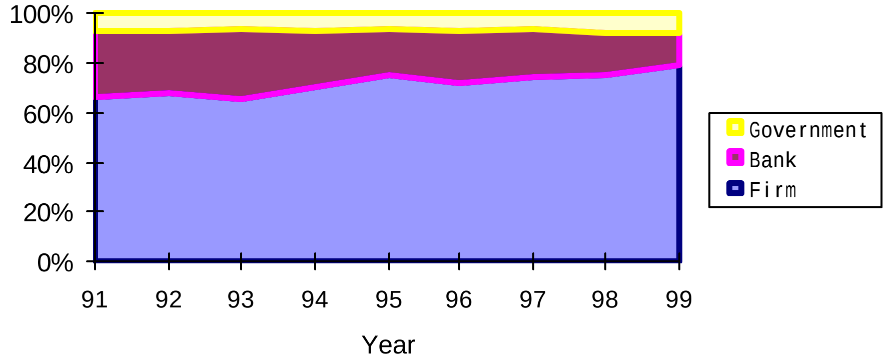
(2) Sources of funds for technology development of large and medium-sized firms.

In the last decade the sources structure has been changing gradually. Government funds as a percentage of total funds are becoming less and less. But firm funds increased fast. In 1987, fifteen year ago, the structure of large and medium-size firm funds for technological innovation was government had 10.9%, firms and banks separately had 44.6% and 38.7%. Up to 1990 government funds felled down to 7.5% and banks' declined at 25.3%, and firms funds increased to 59.8%. After 1990 the above trends keep continuously. In 1999 government funds was about 7.5%, and firms had a further increase and reached at 78.7%. On the other side, banks funds declined at 12.6% (Figure 2).

If examining the total amount of funds from different sources, we find all these sources had a significant increase from 19.3 billion Yuan in 1991 to 68 billion Yuan in 1999. Funds from firms increased from 12 billion Yuan in 1991 to 51 billion Yuan in 1999.

But the amount of funds for technology development of large and medium-sized firms is the same data of firm funds used in Sources of Funds for Science and Technology shown in (Table 3).

Figure 2. Sources Changing of Funds of Large and Medium-size Firms for Technology Development (1991-1999)



Source: China Statistical Yearbook 0n Science and Technology2000, China Statistics Press 2001.

Majority of high-tech firms are small firms. In order to examine the sources for financing Technological innovation of high-tech firms in China I did a survey in the core park of Zhongguancun Science Park ------- Haidian Science Park. The results showed most funds take technological innovation by internal funds; the following sources based on its importance are bank loans and government program for science and technology. Only small parts of firms have opportunities to get venture capital and angel capital (Table 4).

Table 4 Fund Sources of High-tech Firm in Haidian Science Park (2000)

Year	International fund	Bank loan	Government S&T Program	Venture capital	Angel Capital
94	86.21	17.24	10.34	1.72	0
95	85.07	20.90	17.91	1.49	0
96	89.19	20.27	13.51	2.7	1.36
97	89.16	19.28	16.87	3.61	3.61
98	90.32	16.13	16.13	2.15	1.08

Note: Data in this table is the percentage of accumulated responses by respondents.

Bank Loans for Science and Technology

Bank loans for science and technology are the special type of loans, which is provided by commercial banks to commercialization and industrialization of achievements of science and technology, and development of new product with requirements of bank business. Bank loans mainly used in supporting national science and technology programs, such as Torch Program, Spark Program, Extension Program and commercialization of 883 Program. According to provision on the bank loans for science and technology, funs from applicant generally should not less than 30% of total requirement for investment. Loan quota for an applicant should among 5 million to

10million yuan (excluding exceptions that the bank accepts). Basically the total investment of a project does no exceed 30 million Yuan.[7]

There is not statistical data of bank loans for science and technology. Reasonable estimation is to sum up bank loans in the national science and technology programs and technology development. Based on this calculation formula total amount of bank loans in China in 1889 was about 22.3 billion Yuan[8].

Venture Capital

Although the first venture capital firm was founded in 1986, unlike the first successful modern venture capital firm in United States, it was closed in 1998[9].

Venture capital industry is a new sector, really began in 1998. At the end of 2001 it was estimated that total commitment venture capital reached about 30 billion Yuan. Contribution of venture capital to technological innovation is still small. Venture capital in China has developed in a short time and with small size. Relatively small funds flowed into venture capital pool. At present, major investors of venture capital firms in China are government (both local and central government) and public listing companies. Government often put the money into the venture capita; firm as the registered capital. The most active regions of venture capital investment are Beijing, Shanghai and Shenzhen.

Moreover, the largest venture capital firm in Beijing, Shanghai and Shenzhen was supported by funds and policies of local government.[10] There are two ways for the government to involve in venture capital. One is investing directly to venture capital firm as an investor. The other is providing funds to set up the science and technology guarantee company.

[7] Science and Technology Committee of China. Temporary Provision on Bank Loans for Science and Technology Development, September 21, 1995.

[8] China Statistical Yearbook 0n Science and Technology2000, China Statistics Press 2001.

[9] China New Technology Venture Capital Company was founded in the beginning of 1986. Its business fields mainly included: doing business with joint-venture or solo investment; short and long term trust investment; financial guarantee and project loans; issuing stock and corporate bonds in domestic and foreign markets; acquisition of technical equipment and export of technology product. At the early phase it looked like success. In the first three years after its setup, annual profit increased from 8.64 million Yuan in 1986 to 46.35million Yuan in 1988.Sources: Economic daily, January 10, 1986; China Financial Yearbook, 1989.

[10] Shanghai Venture Capital Company, approved by Shanghai government, received 600 million Yuan from local fiscal department, is a stated-own company; Shenzhen Innovative Science and Technology Investment company, founded in 1999, registered capital in 700 million Yuan, local government invested 600 million Yuan.

For the government actions in venture capital the current focus on direct investment should be changed into creating better environment conditions. Comparing with western countries' actions we can see the difference between China and them (Figure 3).

Figure 3. Comparison of Government Venture Capital Tools

Tool Name	United States	Japan	Israel	United Kingdom	Germany	China
Equity Investment	☆	☆	☆☆		☆	☆☆
Loan		☆☆		☆	☆	☆
Subsidy	☆	☆	☆☆	☆	☆	☆
Tax Incentive	☆☆	☆☆		☆☆		
Loan Guarantee	☆☆	☆☆		☆☆	☆☆	☆☆
Government Purchasing	☆☆	☆	☆	☆	☆	

Tax incentive and government purchasing are two blank field for Chinese government. According to our expert questionnaire analysis on government venture capital Chinese government should in particular attach importance to learn the experiences of tax incentive, loan guarantee and government purchasing in other countries.

Public listing company play active role in promoting technological innovation through joining venture capital. The top three motivations attending venture capital are searching or cultivating new projects with potential growth, hopefully acquiring the newest information on the relevant industry sector, and becoming more popular. Since four years history for the earliest participants attending venture capital is too short, public listing companies do not get profit from their investment in venture capital as a whole. Rate on investment less than 10% accounted for 53% in the public listing companies. The rest of the firm did not have any profit. The most common way that public listing company invested in venture capital is co-investment with other public listing companies and without requirement for holding the firm.

Major sources in venture capital fund in the United States, such as pension fund, insurance companies and endowments do not become the sources of venture capital in China. Since the difference existing in the financial system, sources of fund venture capital in China has quite different characteristics from the United States in the aspects on the form of organization, behavior, exit route and incentives (Table 5).

Table 5. Characteristics Comparison of Venture Capital Between US and China.

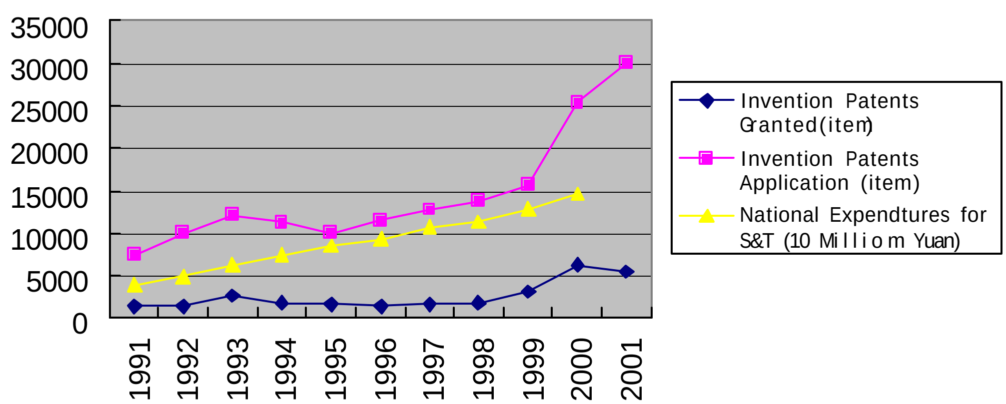
	China	**United States**
Financial System	Based on bank	Based on market
Form of Organization	Limited company	Limited partnership
Sources of Fund	Government, public company	Pension funds
Exit Route	M&A	Stock market
Incentive	Weaker	Stronger
Contribution to Technological Innovation	Not obvious	Obvious

Performance of Technological Innovation

Amount of invention patent of application and granting

We did not use the total number of three types of patent. We select two indicators, amount of domestic invention patent of application and granting, to measure technological innovation performance. Because invention patent significantly represent the capability and potential of technological innovation. Since 1995 applications for invention patent has grown fast. After 1999 a much increase in application for invention patent has appeared. Correspondingly, granted invention patents also raised up. It is ease for us to find that during 1991-2000 funds flowed into science and technology kept on growing. If considering other two types of patent, we can find the greater 9rowth rate in patent application and granting.

Figure 4 Invention Patents and Expenditure for Science and Technology

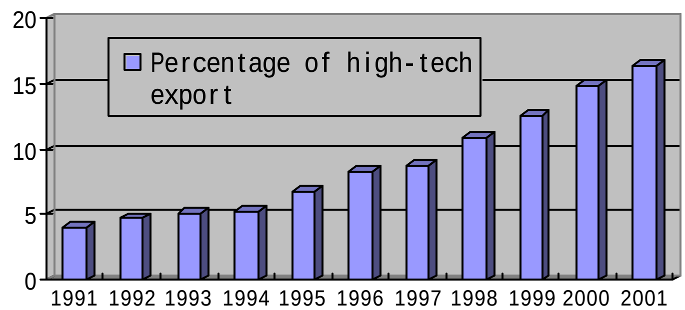


Source: China Statistical Yearbook on science and technology (2000), China Statistics Press.2001; Annual Report of Bureau of Intellectual Property Right of China (2000).

Degree of Technology Deepening

Degree of technology deepening means the percentage of high-tech products exort as the total export of a nation. Comparing with developed countries, export of high-tech products in China is lower. However, the degree of technology deepening has been increasing during 1991 to 2001. Increasing of the degree of technology deepening in China predicts that technological innovation capability has increased rapidly.

Figure 5 Change of Degree of Technology Deepening in China (1991-2001)



Source: China Statistical Yearbook on Science and Technology (2000), China Statistics Press. 2001.P212.
In which datum in 2000 and 2001 comes from website of Ministry of Science and Technology, data in 2001 is the amount of the first seven months.

In 2001 the degree of technology deepening of China reached 16.4%, much higher than the 4% in 1991. Average growth rate of the degree of technology deepening was about 28%. If we hope to keep on this growing trend the key is to improve the capability in technological innovation. The necessary measures we should consider are expanding the financing channels and increasing the financing efficiency.

Conclusion

Internal funds of firms are the most important sources for technological innovation in China. External sources of fund are mainly from (local and central) government and banks. Equity market and external equity financing channels play a limited role for technological innovation. Increasing inputs of fund can spur innovation. Since the middle of 1990s amount of invention patent in application and granting has increased fast. On the other side, the degree of technology deepening changed rapidly. Ali these indicate that with growing inputs of fund technological innovation in China becomes much more active. Capability in technological innovation is reinforcing.

The problems we need to explore further are as following. What are the efficient ways for government to spur innovation in China? How can bank loans for science and technology work well and bring benefit to both bank and technology firm? As for equity market, how does China complete equity capital system, especially venture capital system for technological innovation? Finally, as the base of research, should we need to revise the standards and methods to collect data of technological innovation funds?

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Valleys of Death and Darwinian Seas
Financing the Invention to Innovation Transition in the United States

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An "Innovation Gap" in the United States?

Four years ago, China's Minister of Science and technology at that time, Zhu Lilan, was interviewed in the People's Daily. The journalist posed the following question: "The "Science and Education for a Prosperous China" policy of the Chinese Central Committee has been in effect for over two years [since 1996] but the results have not fully met expectations. Why is this so? How as Science Minister will you implement this policy so as to realize its full potential?" Former Minister Zhu replied: "The main reason why results have fallen short is that there is inadequate investment in S&T. Starvation of funds for science is an international problem—it even occurs in wealthy countries like the US."[1]

Of course, Former Minister Zhu was correct. As Nobel Prize winning economist Kenneth Arrow pointed out in 1962,[2] a system of decentralized competition may fail to achieve optimal resource allocation whenever products are indivisible (marginal cost pricing rules apply imperfectly), economic actors are unable to appropriate the full returns from their activities (social and private benefits diverge), and/or outcomes are uncertain (future states of nature are unknown). All three of these conditions hold not only for basic science, but also for invention and the invention to innovation transition.

Recent trends in the global economy have reinforced this point. As former Undersecretary of Commerce Mary Good (now President of the American Association for the Advancement of Science) remarked in 1997: "As the competitive pressures of the global marketplace have forced American firms to move more of their R&D into shorter term product and process improvements, an 'innovation gap' has developed… Sit down

[1] Renmin Ribao (People's Daily), March 30, 1998.
[2] K. J. Arrow. "Economic welfare and the allocation of resources from invention." In R. R. Nelson, editor, *The Rate and Direction of Inventive Activity: Economic and Social Factors*. Princeton University Press, 1962.

with a group of venture capitalists. The funding for higher risk ventures… is extraordinarily difficult to come by."[3]

The existence of an "innovation gap" is controversial. Skeptics point out that the part of the financial system that specializes in investing in high risk new enterprises—the venture capital industry—has grown dramatically in the last five years. Venture capital funds disbursed to firms reached a peak of over $100 billion in the year 2000, before dropping off to $37 billion in 2001. Interpretations vary. The White House has recently justified reductions in support to the Commerce Department's Advanced Technology Program with the statement that "the overall growth in venture capital suggests private funding is available for high-technology projects." In contrast, technology business leader Bill Joy of Sun Microsystems observed in July of 2001 that "a couple of years ago, even the bad ideas were getting capital. Now we have gone too far in the opposite direction, shutting down investment in good ideas."[4]

We think we understand the (U.S.) research and invention enterprise, much of it publicly funded. We also think we understand business case management and new firm creation, mostly privately funded. But the question remains: Do we understand what goes in between?

Basic research and innovation are inherently coupled only in a few contexts, importantly including

- military procurement of advanced systems, and
- corporate R&D in the core of the business.

In other contexts, however, basic informational and contractual problems pointed create obstacles to funding of the invention to innovation transition.[5] These contractual and informational problems have led some to describe the stage of the technology process between invention and innovation as a "valley of death" for technology entrepreneurs. In order to emphasize the dynamism in this region of the innovation space, we prefer to employ the term "Darwinian Sea."[6]

The research that Professor Branscomb and I have undertaken over the past two and a half years, supported by the Advanced Technology Program, is intended to inform this

[3] Testimony before the U.S. Senate Governmental Affairs Committee. Quoted in Gompers, P.A. and J. Lerner. 1999. *The Venture Capital Cycle*. Cambridge: MIT Press, p. 3.
[4] *Businessweek*, July 2001.
[5] Arrow (1962), Zeckhauser (1996), and Branscomb and Auerswald (2001, 2002).
[6] See paper submitted by these proceedings by Lewis Branscomb.

debate.[7] Our work has led us to five core findings regarding the financing of the invention to innovation transition in the United States.

1. Most funding for technology development in the phase between invention and innovation comes from individual private equity "angel" investors, corporations, and the Federal Government—not venture capitalists.

Of $266 billion that was spent on national R&D by various sources in the U.S. in 1998—the most recent year for which comprehensive and reliable data were available at the time of the research, and probably a more reliable benchmark of innovation funding activities than 2000 when markets were at their historic peaks—less than 14% flowed into early stage technology development activities. We conclude that between $5 billion (2%) and $36 billion (14%) of overall R&D spending in 1998 was devoted to early stage technology development. The rest supported either basic research or incremental development of existing products and processes.

Although the range between our upper lower and upper estimates differs by several billions of dollars, the proportional distribution across the main sources of funding for early stage technology development activities is surprisingly similar regardless of whether we employ restrictive or inclusive models. Given either model, expenditures on early stage technology development by angel investors, the Federal Government, and large corporations funding "out-of-the-core business" technology development are comparable in magnitude. Early stage technology development funds from each of these sources greatly exceed those from state programs, university expenditures, and the small part of venture capital that supports early stage technology projects. Notably—even excluding as we do the impact of government procurement—the Federal role in this process is substantial: in our estimates roughly 30% of the total early stage technology development comes from Federal R&D sources.

Venture capital firms are critical financial intermediaries supporting new high-growth firms. Why, then, is the role of the venture capital industry in funding early stage technology development not dominant? Popular press accounts notwithstanding, venture capital firms are not in the R&D business. Rather, they are in the financial business. Their fiduciary responsibility is to earn maximal returns for their investors. They do this through a complex set of activities that can be summarized as buying firms low and selling them high. Venture capitalists do indeed back high-growth new ventures, and in many cases, though not the majority, they support firms that are bringing radical new technologies to market. However, even when venture capitalists do support technology-

[7] Branscomb and Auerswald, *Between Invention and Innovation*: *An Analysis of the Funding for Early Stage Technology Development*, report to the Advanced Technology Program, forthcoming (2002). See also <www.fundinggap.com>.

based enterprises, they prefer to support ones that have at least proceeded beyond the product development stage—that is, firms that have completed the early stage technology development that is the focus of this study. As the median size of venture capital deals has increased and the pressure to provide attractive returns to investors in mammoth funds has intensified, venture capital has tended increasingly to flow to projects in later stages of development and to already-proven technologies. For all these reasons, trends in venture capital disbursements should not be confused with trends in the funding of early stage technology development.

2. Markets for allocating risk capital to early stage technology ventures are not efficient.

Entrepreneurs report a dearth of sources of funding for technology projects that no longer count as basic research but are not yet far enough along to form the basis for a business plan—a scarcity Dr. Mary Good, former Undersecretary of Commerce for Technology, has termed an "innovation gap." At the same time, venture capital firms and other investors are sitting on record volumes of undisbursed cash, with over $70 billion currently idling in funds raised during the boom years.

We should not be surprised that technology entrepreneurs experience an apparent shortage of funding while undisbursed cash sits idle. Whether or not efficient markets exist on Wall Street may be an open question. However, *efficient markets do not exist for allocating risk capital to early stage technology ventures.* One often cited reason for such inefficiency concerns fundamental limits on the ability of investors in early stage technology ventures to fully appropriate returns from their investments. We focus on a second reason: serious inadequacies in information available to both entrepreneurs and investors. Early stage development involves not only high quantifiable risks, but also daunting uncertainties. When the uncertainties are primarily technical, investors are ill-equipped to quantify them. For new technologies that have the potential to create new product categories, market uncertainties are also high and similarly difficult to quantify. The "due diligence" that investors in venture capital funds require of managing partners and that angel investors require of themselves is intrinsically difficult—and getting more so as both technologies and markets become increasingly complex.

Up to a decade is required for the transition from invention to innovation. Given technical and market uncertainties, venture capitalists, angels, and bankers prefer to wait to see the business case for a new technology rather than funding speculation. The technical content of the business proposal must be sufficiently well established to provide reliable estimates of product cost, performance, and reliability in the context of an identified market that can be entered in a reasonable length of time. It is the funding of this technical bridge—from invention to innovation—that is the focus of this study and is the basis for the notion of an "innovation gap.

3. Despite (or in response to) market inefficiencies, many institutional arrangements have developed for funding early stage technology development. This suggests that funding mechanisms evolve to match the incentives and motivations of entrepreneur and investors alike.

Champions of early stage technology projects make use of a wide variety of funding options to keep their projects alive. These include not only successive rounds of equity offerings, but also contract work, income from licensing patents, the sale of spin-off firms, and old-fashioned cost-cutting. While each of these options is associated with its own costs and benefits, entrepreneurs do not play favorites among them when it comes to keeping their projects moving forward.

In contrast to institutional sources of equity and debt capital for advancing existing businesses incrementally, the transition from invention to innovation is financed by a great variety of mechanisms, with new ones being created every day, including angel networks and funds, angel investments backed by bank debt, university and corporate equity investments, seed investments by university and corporate venture capital programs, and certain experimental R&D programs run by Federal and State agencies.

4. The conditions for success in science-based, high-tech innovation are strongly concentrated in a few geographical regions, indicating the importance in this process of innovator-investor proximity and networks of supporting people and institutions.

If early stage technology development investments from all sources are distributed as non-uniformly as venture capital investments, then they are concentrated in a few states and a few industries. This would be expected, for our research results suggest that angel investments are even more locally focused than venture capital. Furthermore, theory suggests that the quality of social capital in the locality where inventions are being exploited is an important determinant of success. Where the social capital is strongly supportive, in places like Route 128 in Boston or Silicon Valley near San Francisco, one might expect not only strong venture capital and angel investments, but a concentration of federal support for early stage technology development and industry supported high tech ventures as well.

While the scope of our recent project has not generally focused on funding patterns at the regional and industry sector level, some important trends are apparent (Part II below offers a highly aggregated presentation of early stage technology development funding flows at the national level).

Geographic Distribution. The geographical distribution of early stage technology development activity mirrors that of innovation-related activity in general. In particular, early stage technology development is concentrated in geographical regions that invest heavily in R&D, that possess developed risk-capital networks and related complementary infrastructure (e.g. specialized law firms, other suppliers), and that otherwise benefit from strong university-industry linkages.

Angel Investors. We found that angel investors provide the most significant source of early stage technology development funding for individual technology entrepreneurs and small technology startups. Since angel investors make the vast majority of their investments close to home, early stage technology development activities, particularly those of smaller firms, are likely to be concentrated in regions with active communities of tech-savvy angels.

Role of State Governments. State governments, while providing a relatively small portion of total early stage technology development funding, play a critical role in establishing regional environments that help bridge the invention to innovation gap. State governments facilitate university-industry partnerships, leverage Federal academic research funds by providing both general and targeted grants, build a technically educated workforce through support of public colleges and universities, and ease regulatory burdens to create a more fertile ground for technology startups. While Route 128 and Silicon Valley arose with little local or state level political support (in part because they had developed the needed networks, stimulated by defense funding, in the 1950s), a number of states have created many of the environmental features needed for successful innovation. Research Triangle Park in North Carolina, for example, was conceived and initiated by Governor Luther Hodges.

These geographical concentrations create additional challenges to champions of early stage technology development projects located outside of favored geographical or market spaces. Such challenges may be of considerable importance to public policy. The implications for public policy will depend heavily on whether the Federal government attempts to compensate for such tendencies toward concentration, or chooses instead to accept them as reflecting the flow of resources to geographical and market areas in which expected economic returns are highest. In subsequent work, we will further explore the causes and implications of inter-regional and inter-industry differences in funding for early stage technology development projects.

5. Among corporations, the fraction of R&D spending that is dedicated to early stage technology development varies both among firms and within industries. The latter variation may be related to industry lifecycles.

More mature industries, such as automotive industry, tend to invest a smaller percentage of R&D into earlier stage technology development than less mature industries such as biotechnology.

Inter-industry differences in % of R&D spent on early stage technology development projects

Booz Allen & Hamilton estimates, from Branscomb and Auerswald (2002).

Industry	% of industry R&D spent on early stage technology development
Chemicals	33%
Biopharmaceutical	13%
Electronics	11%
Equipment	10%
Telecommunications	10%
basic industries	7%
automotive	3%
computer software	0%

A team from the management consulting firm of Booz Allen & Hamilton that worked with us on our project estimated (by extrapolation from reports from interviewed firms) overall corporate spending on early stage technology development to be approximately $13 billion annually, or 9% of total corporate R&D spending. The inter-industry distribution was estimated is given in the table above. Spending was found to differ widely by industry, as well as by company within specific industries.

Planning of Innovation?... “Anchoring one side while letting the other side go free.:

Our results support the view that fundamental contractual and other obstacles limit the extent to which decentralized markets can efficiently allocate resources. The large observed role of the federal government and large corporations in the funding of the invention to innovation transition leads us to the strategic question: Can innovation be planned? Here the Chinese phrase "anchoring one side while letting the other side go free" offers an interesting point of reference for analysis.

In the same 1998 interview with the *People's Daily* that I quoted above, former Science and Technology Minister Zhu Lilan identified the following as the number one problem that needed to be solved "in order to make the vision 'Science is the first productive force' come true":

> The transformation of scientific results into new technology and products is slow. Reform is the solution to the problem. We need to link science more closely with production so that science and technology can contribute to the development of the national economy. The ratios of investment in science and technology in foreign countries is roughly 1:10:100 where research spending is 1, development spending is 10, and commercialization spending is 100. But in China the ratios are roughly 1:0.5:1000. Therefore we need to look closely at the subjective and objective conditions and environments that slow down the transfer of scientific and technical results to industry...

I would like to propose that the challenge described here by former Minister Zhu parallels that faced by the leading technology corporations in the United States in the 1960s, 70s, and 80s. These large companies generated many basic science breakthoughs in noted research facilities such as Bell Labs and the Xerox Palo Alto Research Center (PARC). Yet, in many well documented and widely discussed cases, these companies missed significant opportunities to turn inventions into profitable innovations. What is worse—in many cases the companies lost not only the inventions, but the inventors, as a result of inadequate support for the invention to innovation transition. The founder of Intel, Gordon Moore (noted also as the originator of "Moore's Law") observed last year at conference at Stanford: "In a pattern that clearly carries over to other technological ventures, we found at Fairchild that any company active on the forefront of semiconductor technology uncovers far more opportunities than it is in a position to pursue. And when people are enthusiastic about a particular opportunity but are not allowed to pursue it, they become potential entrepreneurs. As we have seen over the past few years, when these potential entrepreneurs are backed by a plentiful source of venture capital there is a burst of new enterprise."[8]

How much innovation is the right amount in a large corporation? A region? A nation? In every case, some "spillovers" or "leakage" occur of ideas, people, projects. Moore continues: "One of the reasons Intel has been so successful is that we have tried to

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[8] Gordon Moore and Kevin Davis, *Learning the Silicon Valley Way*, paper prepared for the Stanford CREEG Conference "Silicon Valley and Its Imitators" July 28,2000.

eliminate unnecessary R&D, thus maximizing our R&D yield and minimizing costly spin-offs. But successful start-ups almost always begin with an idea that has ripened in the research organization of a large company (or university). Any region without larger companies at the technology frontier or research organizations of large companies will probably have fewer companies starting or spinning off."

A similar tension faces regions and nations as they struggle to encourage the "horizontal" connections between researchers to spur invention, at the same that they encourage "vertical" connections between technologists and business executives in achieving the invention to innovation transition. In his Industrial Research Institute Medalist's Address provocatively titled "The Customer for R&D is Always Wrong!", Robert Frosch (former head of research at General Motors and Administrator of NASA, among other distinctions), offered the following observation:

> There is a kind of Heisenberg uncertainty principle about the coordination connections that are necessary in R&D. One needs all of these deep connections among kinds of knowledge, and the ability to think about the future, that works best in an institution that puts all those people together. One also needs connection with the day-to-day, market thinking, and the future thinking of the operating side of the business, which suggests to many that the R&D people should be sitting on the operating side of the business.

This is an insoluble problem; there is no organizational system that will capture perfectly both sets of coordination… There is no perfect organization that will solve this problem—the struggle is inevitable.

Neither the United States, nor its venture capital firms, nor its large corporations, have arrived at the perfect organizational structure to manage innovation. To my knowledge, no such perfect organization exists elsewhere. If Bob Frosch is correct (and I think he is), even in theory, fundamental contractions inherent in the "planning of innovation" suggest that it is misguided to aspire toward elegance, symmetry, and efficiency in this context. In the Darwinian Sea, the struggle is inevitable—not just the struggle between aspiring technologies and their champions, but also the struggle between institutional forms and approaches to the management of innovation. Achieving an appropriate balance between order ("anchoring one side") and flexibility ("letting the other side go free") is a fundamental challenge facing technology managers in the United States, China, and elsewhere in the world.

G. Innovation Networks and Social Capital

Cluster Development in the United States: Some Possible Lessons for China

Denis Simon[1]
Monitor China

Today, I want to talk about the results of a study that Monitor Group conducted in collaboration with the Council on Competitiveness. The final version of the study was released in December 2002. It is a study basically of the relationship between regional competitiveness and innovation. Given some of the issues we have discussed over the last day and a half, I thought that this would be a very appropriate topic. For those of you who want a full copy of this study, if you go to www.compete.org, you can get a copy of it or you can also get it on the Monitor Group website.

Now, the basic essence of the model that underlies the study is the belief that if you want to look at the sources of prosperity, you have to go back to the foundations of that prosperity, and that means beginning from the roots of innovative capacity. The basic notion is that the sources of prosperity are not inherited, they are, in fact, created. But, in contrast to the views of some people who believe that government is the principal engine behind the creation of prosperity, the reality is that economic prosperity comes about because of the nature of competition and the degree to which government can frame the environment that will make it attractive for firms to come together to form what ultimately are called clusters. By analyzing the formation of clusters, the development of clusters, and the management and growth of them, we can better understand the new sources and location of innovation. Now, the best example, or one of the best examples, that is illustrates this point is the California wine cluster. I believe that the Northern California experience is a good example of how different forces come together to form a very active, vibrant cluster. Multiple actors played a role in the development of this cluster. Front and center are the growers and the wineries themselves, who are engaged in growing the grapes and doing the processing. But, these players are supported, aided and assisted by active ties with actors on the grape stock side, fertilizer industry, and agriculture organizations--all the way down on the other side to the wine making

[1] Denis Fred Simon is Dean of the Lally School of Management and Technology at Rensselaer Polytechnic Institute in Troy, NY. He assumed that position in July 2002. This presentation was provided while Dr. Simon still was employed by the Monitor Group, though it does not necessarily reflect the opinions and views of the Monitor Group.

equipment companies, the tourism industry, the food industry, and even the educational institutions that are nearby, such as UC Davis, and a number of other institutes in the region. This cluster is basically believed to be one of the most successful in the United States and actually it really does not fit our image of the type of high technology businesses such as semiconductors or some biotech we usually associate with clusters. The point is that clusters are not defined by technology, but by the fact that there are economic forces at work that form the glue that brings all of these players together in a synergistic fashion.

The clusters of innovation project had a number of objectives at its inception. Those objectives had to do with understanding the composition of regional economic growth, the process of cluster development, how innovation arises in those clusters, what kind of lessons could be learned, and obviously developing a methodology that could have some prescriptive value for decision-makers in government, industry and academia. And, those of you who know about my work in China may understand, one of the reasons I got interested in this specific Monitor study was because I think that this methodology has the potential to be used in the Chinese case and that somewhere in the future, this would be an excellent model for China to study and try to apply the key principles. There were some very unique data sources used to inform this study and one of them comes from the cluster mapping project data at the Institute for Strategy and Competitiveness at Harvard Business School. That data set includes information about 172 different economic clusters. The database contains again information about employment, wage levels, etc. The study also was informed by a series of surveys that were completed, totaling over 1,000 surveys and about 260+ associated interviews. So, it is a very in-depth study and it is the first time some of this data has been pulled together to help promote a deeper understanding of the actual workings of the cluster formation process.

Five clusters were studied in the report. Of note is that Silicon Valley in California was not one of those regions contained in the report. The Monitor Group, under the sponsorship of the Council on Competitiveness, studied Wichita, Pittsburgh, San Diego, Atlanta, and Research Triangle in North Carolina. Each of these regions has certain core industries attached to their specific clusters. Again, there are some very interesting ones here for China to consider, particularly Pittsburgh. I believe that Pittsburgh is a very appropriate case to examine given the situation in places like northeast China and some other industrial Chinese cities that might be interested in learning how to move from so-called “sunset industries” into so-called “sunrise industries.” I think you’ll see there’s a key commonality about these clusters and that is that some of them were formed, survive and are sustained by merging together traditional strengths with new strengths that have been developed over time. So, the focus of this talk today really is to follow through with an analysis of some of these—not all of them—and to highlight some of the key findings of relevance for the Chinese case.

Originally, this was a presentation that was put together for a day-long series of meetings, so I have curtailed some of it. But, just to give you some of the essence of what is important here, if you looked at innovation across regions in the United States, the first thing that you obviously see is that the average number of patents per 100,000 persons is about 20. You can see that over the areas covered in the study, there are only a few areas in the United States that are really what you might call "innovation-intensive" (using patents as a measure of innovativeness). So, there's a high degree of concentration of innovation in the US, with most areas of the 172 economic areas I mentioned from the HBS database basically not extremely active in terms of technological innovation. But, hen you look specifically at those areas that are active in terms of technological innovation, there's a very interesting correlation. The areas with the highest wages and where wages are growing the fastest have the highest positive correlation with those areas where there's a high degree of patenting and therefore a high degree of innovation. One of the main things that is important about this study, I think, is that Monitor does not want to examine correlations simply with aggregate growth, but with growth that increases the livelihood and the welfare of the people who live in a specific area. If living costs rise faster than the rate wages increases, then, in a sense, you may have growth, but you don't really have increased prosperity. So, the key argument is that in these innovation intensive areas, or these cluster areas, you tend to have very high degrees of both prosperity in terms of wages and a high degree of innovativeness.

Now, the kinds of measures that were used in this study reflect a combination of traditional economic measures, such as employment growth, wage growth, etc. and a group of innovation output measures, such as patents, number of new businesses established, venture capital investment, number of initial public offerings, and the number of fast growth firms as manifested in the number of new firms on the Inc. 500 list. You can see that a lot of the things we've talked about over the last day and a half are included in the discussions about measures of innovation output. And, again we could have a lengthy discussion about this issue, but I think this represents a reasonable approach to creating a composite of innovativeness. Just to take an example, this was the one measure used for the city of Atlanta. Monitor grouped together all the measures and tried to highlight where the city was strong and where it was weak in terms of innovative capacity. For example, with respect to innovation output, Atlanta is very weak in terms of the national average. The analysis shows that Atlanta basically needs some help if it's going to continue its high prosperity growth.

The basic analysis contained in the cluster study looked at several different types of clusters, e.g. trading clusters versus local clusters. I think this is a very important distinction. Trading clusters are those clusters where there's a high degree of interaction between one cluster and a number of other clusters, not only in the geographic area, but could be across the country. So, these are clusters that are engaged in a lot of economic and technological exchange with other clusters in the United States. Contrast this type of cluster with the so-called "local clusters," which are very much like enclaves. They exist, but they are localized in their orientation and there's not a lot of sharing, not a lot of interaction with other clusters. And, you can easily see the overall differences in their respective performances, particularly in terms of wages, in terms of relative productivity, and obviously also in terms of patents per 10,000 employees. So there's a clear difference between these two types of clusters. You might say that one group is very energized to look beyond their cluster, while other clusters are very inward looking. There are many clusters around the United States that one could choose to study from this perspective and this is just a picture of what some of those look like.

From a macro analytic point of view, there is a certain amount of economic activity that's going on in any particular area and it's measurable. For example, let's take the Research Triangle in North Carolina. This area is composed of six counties and three communities. In fact, they have been growing quite substantially. So, let's start with some of the implications that come out of the first part of the study. Starting off, to conduct this type of research and analysis, you have to define which regions you want to focus on and not just formal political jurisdictions and assume they define an economic region. There are processes, relationships and channels of commercial exchange that form a kind of natural economic zone, you might say, and it is precisely because of the nature of the economic linkages that one can bound them into an object of inquiry. So, sometimes it is better to think in terms of a broader geographic designation then to think in terms of just political jurisdictions. From a policy perspective, this bounding becomes very important because it has lots to do with the formulation of an appropriate (and relevant) economic strategy to build on. Where there may be unique assets, the definition of the so-called "boundaries" again becomes very, very important. It also may be useful to think in terms of clusters of clusters, not just one cluster, and as will be clear in a little while, as in the case of Massachusetts, there's often a very interesting overlap of clusters that help to support clusters of clusters (three in the case of Massachusetts). That can be a very important key to growth.

Finally, understanding why there is a unique innovative capacity present in many clusters is a very important matter. It takes time for each of these clusters to grow. We can appreciate this by looking at the growth experience of Research Triangle all the way from the 1950s up until the year 2000. So, again, I want to emphasize that it takes time for these places to develop. This is a 50-year period in which the Research Triangle has developed. And one of the issues that Research Triangle faces right now is, now that it's done all of the key things to get to where it is today, where does it go from here? And, how does it sustain its growth during the next phase of development? In many respects, Research Triangle has hit a sort of a bottleneck. Among the kind of factors that influenced the growth of these regional economies, there is nothing here that's particular surprising. No magic formula has been used. What's critical is the way that each of the key factors has played a specific role, some of them in a little bit different manner than most people might expect, particularly in terms of the role of government.

Let's look at the role of the defense sector, for example. The presence of the U.S. military early on in certain regions in the US gave birth to the aerospace industry and later had some linkage to power generation and communications. And, in the 1950s, when bio-science started to be built up, it eventually gave birth to the biotechnology and medical devices industries. These became the foundation building blocks for what eventually has happened in the Sand Diego area. And, you can see they've gone from a focus on hospitality and tourism to transportation and sporting goods and leather goods. So, there has been an evolutionary trajectory, and its not that you do it once and it stays where it is. It's a very dynamic development model. This holds true regarding the evolution of all of these regional economies. The fact that it takes time and the fact that there are multiple factors at work are all critical things to consider.

One last point and this has to do with leveraging the unique assets that are present. This is very, very important. Those of you who have read Michael Porter's work know that this point specifically comes from the Diamond Model, which is basically the core feature of Porter's model regarding how regional development and local development occur. There's obviously the role of government, which in the Porter model has a specific role. Again, it's the conditioning role that government plays, not the direct role that is significant. Porter's model, and I believe the underlying philosophy of his work on competitive advantage (some might call it the "ideology" if you want to say that), is to show that government should, at times, simply stand back and let the private sector do its thing. I think that's one of the essential conclusions that comes out of this study as well. Now, if you look at a couple of the related conclusions that come from this, obviously establishing a strong, physical information infrastructure is quite important. A strong K-12 education system also is important. One of the things you find in many of the selected cities as well as in the clusters that are built around cities, is that the education system for kids is pretty poor and therefore executives don't want to move into cities with their families because they are not willing to send their kids to local schools (because of quality concerns). This becomes an inhibitor for them to relocate into those areas that want to attract new investments and new companies. So, the ability to bring about substantial growth spurts really is dependent on having an attractive infrastructure and living environment. Governments can and do play an important role in crafting these things in both a positive and negative sense.

Obviously, companies do not want to operate in very high cost areas, where a lot of their profitability is going to be taken away by paying high rents and the real estate costs, taxes, etc. Poor coordination among local jurisdictions can constrict efforts to improve the local business environment. This probably sounds like an indictment of government. But, it is not that far removed from the reality the one often finds in these situations. In many ways, local governments and their related agencies fight one another for power, for authority, for control, and therefore sometimes create real obstacles to the growth of these regions. This appears to be the case in Research Triangle today. And, if you just take some of the issues that were raised in the study re: Atlanta, fragmentation across the local government system also has produced many problems. There was a lot of infighting, with government agencies and companies fighting against each other rather than working together. In some respects, this sounds like the situation one frequently finds in China, where concerns about economic scarcity produce fierce infighting and bureaucratic competition.

Research Triangle is the product of three main regions with three different cultures and three different styles of government. Charlotte, for example, is very hierarchical, which is another separate problem. In some cases, a very pluralistic kind of governmental structure can impede the development of clusters because it is hard to get the players to mesh together and synchronize in a smooth, coherent and collaborative manner. So, the government does have a strategic role, especially in terms of the influence it has on the business environment. But, it is not always necessarily a positive role. When it is working in the right ways, however, it can be a very powerful force. Massachusetts is a good example, one that I know Lewis Branscomb has talked about and has been involved in directly or indirectly. The government apparatus in place for promoting the state's economic development was created to help, in effect, makes sure that Massachusetts' growth was innovation-intensive. It has helped to drive the trajectory of the economy in specific directions, and support all the different industry clusters around which there have been different government as well as corporate and academic groupings. Now, again taking the positive and the negative aspects of government, the San Diego study highlights both sides of the equation. You can see that in some instances, the founding of UCSD and the funds from San Diego State were all very positive. But, then again, we also can see some negative aspects as well. For example, the FDA, in terms of the bio-tech area, basically did not coordinate its activities and policies very well with the state FDA, and therefore there were specific problems in terms of moving drugs from the laboratory into commercial use. There are a couple of other examples of negatives and positives coming from government. In each of the different cities, or cluster case studies, it is necessary to focus on both the positives and the negatives to fully understand the respective growth experiences and limitations of each location. Finally, the experiences documented in each of the cluster studies highlights the need to think about the issue of strategic transition. In essence, success with one strategy almost necessarily creates the need for a new strategy over time. These strategies cannot be static if they are to lead to sustainable growth over time.

Let me make a couple more comments about the clusters in particular. Why are clusters important? Well, I have tried to outline here why they are critical. Clusters are important because of the efficient access they give to specialized inputs, employees, know-how, etc. They help centralize things acting as a magnet to pull together critical resource streams from government, business, and academia. They also serve as a vehicle to help coordinate activities and investments across firms. At their most effective level, they provide for the fusion of best practice. And, they basically help to establish performance comparisons so that those who are working in these clusters understand what level of activity is expected. Moreover, they also stimulate and enable innovation and ultimately help to facilitate commercialization of ideas and know-how. So, in the final analysis, the cluster is something that, if you participate in it, you are part of a "hot house" environment that hopefully will work to stimulate your organization's own performance and the other guy's performance as well.

From the corporate perspective, the fact that there is competition inside the cluster can be a very good thing. In other words, one of the things that diminishes the viability of clusters is when one firm comes in and tries to kill the competition. The competition in the clusters is part of its life blood, and that's a very important part of understanding the psychology and dynamism of these clusters.

Now, the one cluster that I'm going to talk about for a minute is the Research Triangle, which is one that has attracted a lot of attention. Two main industry clusters—communications and biotechnology--and the institutions to facilitate collaboration were built around the Durham, Chapel Hill, and Raleigh area. Now, the communications cluster is one of the most interesting ones among all of those studied. Firms such as Cisco and Nortel have fairly significant operations there. This cluster is number seven in terms of communications clusters in the United States, right below San Francisco, Boston, Chicago, and New York, LA, and Dallas-Fort Worth. Now, if you look at this cluster in terms of its particular strengths, computer equipment and office machines stand out. If you examine where it's most competitive, it's in communications equipment. Once we move beyond these specialty fields, it then starts to show some weaknesses. And one of the things the analysis shows is that it is particularly weak in terms of specialized services like banking and accounting, legal services, and also venture capital firms and angel financial networks. One of the things about this area, therefore, is that if it's going to grow in the future, it's going to have to figure out how to bring those specialized financial and legal services and venture capital into stronger play.

If we look at the innovation environment in the Research Triangle, we can see a lot of weaknesses and what I want to do rather than spend time specifically on the communications segment one is just talk about the overall weaknesses of the cluster. The major barriers to the future growth of Research Triangle, for example, can be found in four or five areas. First of all, there seem to be too many parochial interests and not enough cross collaboration among all the local leaders. Second, the region is plagued by a weak transportation infrastructure. As the cluster has grown, the transportation system has not kept pace with it. So, you now have major transportation bottlenecks in the area. The school system has been a third major problem and there hasn't been a comparative development of the school systems to coincide with the development of the whole economic area. Fourth, the development of local cultural institutions has lagged as well; some day it's still a cultural backwater. In fact, the South, to many people, is a cultural backwater and many people in leading-edge industries feel like the South is not the place they want to raise their family, for better or for worse. They also have failed to leverage some of their positional strengths in textiles and plastics, and basically their extensive focus on communications and biotech has led them to ignore some of the areas where they do have some unexploited capability. When the study was done and Monitor talked about textiles and plastics, many of the people in North Carolina were surprised. They thought those were dead industries. But, in fact, those are industries that have survivability and ought to be part of the future clusters that are being developed.

Two other things are important to consider. One is the absence of a major corporate headquarters in the region. Among the many companies that are down there, while some have major operations, there are not that many with major headquarters. And, history shows that headquarters beget other headquarters. When the first anchor headquarters is in place, other companies will put up their respective headquarters in the region. But, right now, there aren't that many headquarters. The one exception is the textiles industry. So, there's a way, perhaps, to maybe incorporate several textile industry companies into a larger geographic cluster. So, the new goal people are talking about is to take the existing cluster, which includes six towns and the three communities, and to create a new, much larger 18 town, regional economic area. So, where we were once talking about an MSA (Metropolitan Statistical Area), which is basically built around an urban center, people are now talking about how to incorporate more areas into a wider regional economic zone. The goal here, basically, is to make sure that this is not what they call Raleighization, which would be a very localized cluster, rather than real regionalization of economic growth.

Now, once again, all this discussion has focused on one development cluster. I also would like to discuss the history of the San Diego biotechnology and pharmaceuticals cluster. We can see its evolution from the 1950s, when the Salk Institute was founded, all the way up to recent days when the well-known Agriculture Discovery Institute was created. The key here is to look at the role of an anchor firm. Anchor companies are very critical to development of clusters, and the study emphasized just how important these were for advancing, both short and long term cluster development. This is a case where Hybrid Technologies formed the anchor role for the whole development of the biotechnology and the pharmaceutical cluster in the San Diego area. The same things were documented in Pittsburgh, Research Triangle, Wichita, etc. So, anchor firms become a critical point of development in terms of overall cluster growth.

As I noted previously, one of the other things that we need to consider deals with clusters which overlap with other clusters. A good example involves the ones which developed in Massachusetts between health, IT, and the knowledge creation or the education industry. You can see that medical information processing, medical software, universities, and medical outcomes measuring all have some critical things in common in terms of their core elements. In these particular industries, during downturns in the economy, these sectors can move and lean to one side or lean to the other side and not be caught up in some of the cyclical downturns in the American economy.

So, what are some of the basic conclusions from the Monitor/Council on Competitiveness study? First of all, there needs to be a substantial economic vision to support and coordinate the multiple activities that comprise the elements of a successful cluster. And, that means bringing together and fostering cooperation among all of the leaders in a particular area. In addition, leadership is a very critical element in the overall development strategy. Second of all, there needs to be some kind of overarching organization that helps to coordinate, manage and routinize the development process. Routinizing the process doesn't mean making it overly bureaucratic. Basically, it means having an organization responsible for information aggregation and dissemination based on a rather complete understanding of what's going on. There needs to be rigorous analysis to understand fully where the strengths and weaknesses are. There also needs to an approach to facilitating and overcoming transitions in these regions, especially in terms of promoting sustained cluster development. And basically, there needs to be an appreciation that there are going to be pitfalls along the way.

So what are some of the actions that can be or need to be taken? Again, there's a long list to be covered, but I only want to talk about the ones for cluster-specific development. There must be an on-going effort to promote cluster awareness. That sounds like something you do with a group of young children! But, this is a real issue. Cluster awareness means that people have to understand that they're part of a cluster and therefore, they have a role to play in the development of the cluster and its interrelationships with other clusters. Moreover, there also needs to be an ongoing diagnostic of the cluster's competitive position. What happened in almost all of the cases mentioned, the five cases, is that each has failed to provide a sustainable model for long term growth. Various clusters became less competitive over time and each one actually didn't realize it until, in a sense, they were shocked into looking at what was happening. Training is another important area that cannot be ignored. Obviously, as mentioned, government participation also is critical. The government serves a core role in terms of recruiting firms to come to these clusters. And finally, widening the institutional membership to include all of the players in a cluster is key as well.

To conclude, let me reiterate that to build one of these clusters requires securing the cooperation of the firms, the government, the educational organizations, and building the networks of collaboration and exchange. The key players must all work together, in tandem, to make the cluster a dynamic institution. Again, this slice of analysis of clusters is only a piece of a very, very large study that occurred over the space of about a year with a lot of intensive data collection. I want to encourage you to go to the website and try to download the full report if you have further questions. With the massive efforts underway in China to stimulate cluster development, there is little doubt that Chinese policymakers as well as technological entrepreneurs could benefit greatly from looking at the Monitor Group's study and extracting those lessons that could be applied to the Chinese experience in places such as Beijing (Haidian), Shanghai, and Shenzhen, among others. This is especially true about the types of strategic partnerships that must be orchestrated for Chinese cluster development to prosper in the year's ahead.

Thanks very much.

Networks and Incentives in Transition: A Multi-level Analysis of China's Pharmaceutical Industry

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Abstract
This paper investigates the institutional and organizational sources of persistence and change in a product innovation system that brings new products to market in China's transition economy, focusing on the interaction between incentives and networks comprising that system. Even after two decades of economic reforms, the research institutes, manufacturers and wholesalers in many state-dominated industries have not moved significantly beyond their functional boundaries established decades ago under the Soviet-style command economy. A case study of the pharmaceutical industry shows that while the system may still be comprised of functionally-specialized organizations, the dynamics underlying this structure have changed dramatically with reforms. Further, organizations are beginning to pursue alternative strategies for creating and acquiring complementary assets, although these are not always in line with overall reform objectives and, in some cases, lead to suboptimal system performance. Suggestions for further research are meant to extend our first steps towards applying network concepts to the analysis of transitional contexts like China.

Keywords: China, innovation network, complementary assets

INTRODUCTION

The result of nearly two decades of economic reforms in China has been greater incentives and expanded managerial choice for pursuing strategies to obtain complementary assets that, under the command system, were allocated by the government (Child, 1994; Whitcomb & Li, 1996; McMillan & Naughton, 1992; Peng & Heath, 1996; White and Liu, 2001). However, actual behavior is an outcome of the overall incentive structure and bureaucratic environment in which these organizations operate (Guthrie, 1997), as well as the set of interorganizational relationships within the organizational field (Burt, 1992; Granovetter, 1985; Uzzi, 1996). In China, these are important sources of inertia, and even after two decades of reforms, most products in state-dominated industries are a cumulative effort of functionally specialized organizations interacting across organizational boundaries. Recently, however, there are signs of emerging variation in the networks that bring complementary assets together to develop, produce and deliver products as organizations respond to a changing incentive structure. This is in line with evolutionary approaches to studies of network structure that highlight the endogenous relationship between an embedded organization's actions and network structure that both guides and evolves in response to that action (e.g., Madhavan et al, 1998; Gulati, 1999).

In this paper, we begin to analyze the sources of persistence and change in two types of networks present in any industry; namely, the *cross-functional networks* through which complementary assets are brought together to bring a product from conception to market, and the *intra-functional networks* through which particular functional assets are created. To understand system and industry-level implications, however, we must look at organization-level incentives and behavior. Any functionally specialized organization may belong to both cross-functional and an intra-functional networks, and we would expect its strategies to respond to the new incentive structure—the need to generate revenues—would affect its behavior in both networks. Therefore, we relate the evolution of these cross- and intra-functional networks to changes in strategic behavior that, in turn, represent the organizational response to changes in the incentive structure.

We begin by relating general discussions of networks and incentives to the types of changes defining China's transition economy. We then analyze changes in the dynamics and structure of the cross-functional and intra-functional networks in on particular context—China's pharmaceutical industry—comprised primarily of functionally specialized organizations: research institutes, manufacturers and distributors. We describe changes in how they 1) bring together complementary assets and 2) create new functional assets. The incentives and choices facing managers of these organizations are representative of those in other industries with a legacy of central planning, state control and functional specialization. While the industry is still characterized by functionally specialized organization, as it was under central planning, the underlying dynamics have changed dramatically. Moreover, we find emerging variation within these networks as managers exercise greater discretion over strategic decisions regarding the acquisition of complementary assets (in the case of cross-functional networks) and creation of complementary assets (intra-functional networks).

NETWORKS AND INCENTIVES WITHIN A PRODUCT INNOVATION SYSTEM

We frame our analysis of changes in organizational strategy in terms of networks and incentives within a particular industrial context. By describing the structure before and since transition-era reforms, we can compare the way in which resources are created and new products brought to market, which we collectively call the industry's *product innovation system*. Our focus follows Nonaka (1994) and Amendola and Gaffard's (1994), who maintain that resource *creation* is the central economic problem rather than the traditional focus on resource allocation. Studies of Chinese institutional and economic reforms have focused primarily on changes in the mechanism for allocating resources. At least as important, however, are the changes in how resources are created. Indeed, reform success will depend not just on resources being more efficiently allocated, but also on better resources being introduced in the first place.

A large body of research on production systems has examined vertical integration and interorganizational relationships in other contexts (Argyres, 1996; Poppo & Zenger, 1998; Sakakibara, 1997; Saxenian, 1991; Storper & Harrison, 1991). This work, however, does not distinguish between cross-functional and intra-functional interorganizational relationships.[1] While obviously related, however, incentives affecting cross-functional and intra-functional interactions and related strategies are different, and these networks may evolve differently.

Therefore, in order to analyze key changes in organizational strategy and industry structure that are taking place in Chinese manufacturing industry during the transition period, we address these two types of networks separately. The first—cross-functional networks—comprise the system through which complementary assets (Teece, 1986), arising from research, manufacturing, distribution and other functional activities, come together to bring products to market (e.g., Callon et al, 1992). We purposefully do not use the term "innovation system", which encompasses a much wider range of actors and activities, often at the national and regional level (e.g., Nelson, 1993; Lundvall, 1992; Edquist, 1997; Liu & White, 2001).

[1] For general reviews of research on interorganizational relationships, see Auster (1994), Grandori and Soda (1995) and, in the particular case of technological collaboration, Dodgson (1993).

While some have drawn attention to the activities undertaken by heterogenous organizational actors (e.g., Callon et al, 1992), we distinguish between the locus of activities and the organizational boundaries around or the governance structure that links these loci. In other words, the functions are not assumed *a priori* to be located within any particular organizational structure. The cross-functional network that brought one product to market may be located within one organizational boundary (as in a vertically integrated firm undertaking R&D, manufacturing, etc.) or involve multiple organizations (as is necessary when the organizations are functionally specialized). In transitional economies, we expect to find a different organizational structure for these activities due to the legacy of Soviet-style central planning and industrial structure, and a different evolutionary trajectory than that found in other nations with different initial conditions.

In addition to the cross-functional network that brings together complementary assets, there is also the intrafunctional network that brings together the same functional activities to achieve scale or scope economies. Producing any functional asset—new product or process technology, manufacturing output, distribution—entails multiple subordinate processes that may be located within one organizational boundary or distributed across many organizations. The intra-functional networks within any industry, therefore, can be extremely sparse if the industry is dominated by organizations that are vertically integrated within functions. Conversely, networks may be very dense and complex if organizations undertake extremely specific activities and these must be linked to other activities in order to deliver a functional asset. Intrafunctional networks will be more dense and complex when, for example, there is extensive collaboration between researchers at different institutes, sub-components and intermediary manufacturing inputs are produced by different organizations, or product delivery is achieved by multiple organizations.

Network characteristics represent the aggregate strategic response of actors in these organizations to the incentive structures in which they operate. Accordingly, the product innovation system and its component cross- and intra-functional networks emerge and evolve in response to organizational strategies which, fundamentally, represent a response to perceived changes in the incentive structure facing managers in those organizations. The basic elements of an incentive structure are the perceived values that decision-makers place on a range of possible goals, as well as their perceptions of trade-offs involved in pursuing particular goals. Personality traits, organizational culture and other cognitive processes, as well as institutional forces, affect managerial perceptions of the relative values of these trade-offs (Scott, 1995).

Managerial incentives to introduce strategic change or not are particularly relevant in transition economy contexts (White and Linden, 2002). Research has shown how a perceived necessity to change, such as in organizations facing a crisis, increases managerial incentive to introduce even drastic changes (Ruef, 1997; Whitley and Czaban, 1998). This is the cognitive basis behind recommending "shock therapy" for state-owned firms, including a rapid move from soft to hard-budget constraints (Kornai, 1990; Walder, 1991, 1995). Similarly, others propose that greater managerial dissatisfaction with organizational performance increases their incentive to introduce change (Greenwood and Hinings, 1996; Sastry, 1997). Of course, this is only salient when managers' personal interests (e.g., pay, career prospects, values) are linked to organizational performance.

Positive incentives for change, however, must overcome considerable incentives against change. Research from diverse perspectives emphasizes that managers perceive change as difficult and risky. Indeed, empirical research supports such managerial perceptions. Introducing change is indeed risky and is associated with an increased short-term survival threat (Ruef 1997; Amburgey, Kelly and Barnett 1993), although those that are able introduce necessary changes are better off in the long-term. The difficulty of introducing fundamental change may also be exacerbated by the power structures within and outside organizations. Often the leaders and others in power have an incentive to maintain the status quo (DiMaggio and Powell 1983). Furthermore, even if they have an incentive to change, a turbulent external environment may discourage them. Managers, however, may be willing to act strategically only if they can predict the outcomes of alternative strategies (Beckert 1999). They are unlikely to make strategic commitments when the "rules" linking means and ends are not clear (North 1993), a particular problem in transition economies (Fligstein 1996; Whitley and Czaban 1998).

CHINA'S PRODUCT INNOVATION SYSTEMS IN TRANSITION

Following the Soviet model of industrial organization, organizations in China's state-controlled industries subject to central policy did not undertake more than one of the functions within the overall product innovation system, and in practice were unable to introduce new products alone. Organizations had functional mandates; e.g., research, development, manufacturing, or distribution. The cross-functional networks that brought together complementary (functional) assets were theoretically but in practice poorly coordinated by central government bureaus (Figure 1). Inevitably, the functional outputs (new product know-how, components and final products, and distribution of those products) were either not transferred efficiently or supply and demand not successfully balanced (Maruyama, 1990; Lo, 1997). This resulted in the shortages and hoarding behavior that Kornai (1980) describes as endemic to the centrally coordinated allocation system in practice. It also created strong incentives for organizations, manufacturers in particular, to vertically integrate within their function because the interorganizational linkage mechanisms were inadequate for providing inputs of adequate quality or quantity to meet production requirements. Product innovation stagnated under this centrally planned system, with little improvement in the quality or range of products produced by these industries.

Economic and organizational reforms, however, have dramatically altered the incentive structure facing managers in the functionally-specialized organizations that still dominate former state-controlled manufacturing industries. Now, essentially all of the functionally specialized organizations that were formerly wards of the state—research institutes, manufacturers, distributors—are under pressure to improve their financial performance. The central government has indicated to most of these organizations that government subsidies will end. For example, from the mid-1990s the government froze the funding levels of many of these organizations, letting inflation (10-20% annually in the first half of the 1990s) set the pace of subsidy reduction. From 1999, over 5,000 applied research institutes were transformed into for-profit organizations, cut off from automatic subsidies and expected to survive from competitive grants or paying customers. Eventually, the government intends such sources to be their primary or only source of funds, perhaps augmented by competitive financing from capital markets.

Such policies and related enterprise reforms have created stronger incentives for research organizations, manufacturing firms, and other types of organizations to increase revenues. Peng and Heath (1996) have questioned the validity in China of the assumption of the "western" strategic choice model of the firm regarding managers' motivation to grow. However, if the definition of growth is limited to increasing financial measures of revenues and profits, this assumption is valid in China today (White, 2000). Such growth has become the central objective in both business operations—state-owned included—as well as in organizations not usually associated with profit motivations, such as research institutes and universities. Certainly, profit-maximizing and strict economic efficiency are not appropriate behavioral models considering the non-economic objectives still assigned to these state-owned organizations (Walder, 1995) and the continuation of soft budgets (Steinfeld, 1998). However, managers can be characterized as profit and revenue-seeking, exhibiting satisfying behavior (March & Simon, 1993) in pursuit of these goals.

While financial performance has become the most important objective even in state-owned Chinese organizations, choosing and implementing means to achieve such ends are proving problematic. To the extent that subsidies, soft loans and other government financial support are steadily declining, most organizations have two fundamental choices: reduce costs and improve productivity or introduce new and improved products and services.

Reducing costs and improving efficiency, however, have proven difficult. Although some researchers claim that both production and productivity in state-owned enterprises has risen (Rawski, 1994; McMillan and Naughton, 1992), there is considerable contradictory evidence. Woo (1997) has documented that state-owned firms showed a one-time increase in efficiency in the early years of reform, but very little in the years after 1984. He suggests that decentralization of management decision-making has not created incentives for managers to introduce technical improvements. Similarly, Walder (1995) has argued that reforms unaccompanied by hard budget constraints have created incentives for managers to allocate funds to non-productive purposes. This is compounded by the government's unwillingness to advocate drastic cuts in the welfare functions of firms for which existing social infrastructure is unable to substitute (Walder, 1991). Further, neither the government nor enterprise managers are willing to risk massive lay-offs that could most directly improve efficiency.

Instead, managers prefer to undertake new activities by which they can increase their revenues. Marketing their original functional activities and services or introducing new products are the primary options they have for increasing revenues, of which they are able to retain some portion.[2] The government also supports commercial activities, especially new product development, through its technology and tax policies, hoping for both improvement in the organizations' fiscal condition and increased tax revenue. Further, as these firms are exposed to increased competition, they are under pressure to respond by introducing new, better and more varied products and services (Fischer, 1989; Rawski, 1994; McMillan and Naughton, 1992).

Given the functional specialization of these organizations, however, introducing new products inherently involves a high degree of interorganizational coordination or, alternatively, investment in internal capacity to produce the necessary complementary assets. The following section describes these organizational strategies, the changing incentives to which these are a response, and the resulting impact on the structure and dynamics of the cross- and intra-functional networks comprising the product innovation system in China's pharmaceutical industry.

NETWORKS AND INCENTIVES IN CHINA'S PHARMACEUTICAL INDUSTRY

China's pharmaceutical industry is illustrative of a major industry that was totally directed by the state and subject to central planning, and transition-era reforms have had a major impact on it. The pharmaceutical industrial bureau, the State Pharmaceutical

[2] Not all firms, however, place equal emphasis on introducing new products. Appendix A contrasts the attitudes of managers at two different manufacturers regarding their product strategies.

Administration of China (SPAC), was newly created in 1981 to take over control and coordination of this industry from the Ministry of Public Health (MPH), which in the past itself had inherited related responsibilities from the Bureau of Chemical Industry. However, SPAC's creation also corresponded to the beginning of enterprise and macroeconomic reforms—the transition period—under which SPAC's role, objectives and activities were to change drastically. Specifically, during the ongoing transition period, SPAC's role has shifted away from coordinating resource transfers among research, manufacturing and distribution (wholesaling) organizations (the change depicted in Figure 1). Instead, it is focusing on its role as a facilitator and regulator; for example, attempting to raise the level of quality of domestic producers by providing guidance for introducing Good Manufacturing Practices (GMP) standards into their operations. This shift was institutionalized in 1998 as the two primary functions of SPAC—industry oversight and commercial activities—were separated. Now, the State Drug Administration (SDA) is responsible for industry promotion, R&D support and regulation, while commercial activities have been spun-off as separate, although still state-owned, firms.[3]

The following sections describe changes in the cross-functional networks through which complementary assets are combined to deliver new products to the market, followed by a description of two intra-functional networks: R&D and manufacturing. For each network, we relate changes in its structure and dynamics to changes in the incentives facing the managers (or researchers) in these originally functionally specialized organizations.

CROSS-FUNCTIONAL NETWORKS

In this section, we describe changes in the way that complementary assets are brought together in China's pharmaceutical industry. While the structure of this network is still characterized by functionally specialized organizations, its underlying dynamics have changed greatly. The following describes the relationships among these organizations, as well their incentives to make, buy or ally to create, transfer and combine functional complementary assets.

Research and manufacturing

During the command economy era, the Ministry of Public Health (MPH) not only oversaw the internal operations of research institutes and manufacturers, but also directed the transfer of research results between them. A manufacturer played a passive role, implementing the technology that was directed its way by MPH and acquiring the necessary equipment using funds also provided by MPH. Similarly, the research

[3] An overview of the Chinese pharmaceutical industry is presented in Appendix B.

institutes could either propose research projects or, more commonly, wait for research programs initiated and directed by MPH. Diffusion of research results was also directed by MPH, with social welfare optimization as its primary objective; economic objectives such as profit were not considered legitimate by MPH.

In 1981, the State Pharmaceutical Administration of China (SPAC) was newly established to take over responsibility from MPH for most pharmaceutical industry research, production and distribution. MPH retained its role of approving products for sale, similar to the Food and Drug Administration's role in the USA. In 1998, SPAC's roles were redefined as the SDA was formed to promote research and the industry overall, as well as ensure manufacturer compliance with operational regulations, especially those related to manufacturing. SPAC's former commercial activities were separated from SDA into purely for-profit firms, primarily in distribution.

After these bureaucratic changes and twenty years of reforms, economic performance of manufacturing firms has joined social welfare needs as a legitimate objective. At the same time, managers are being allowed more discretion to consider and enact strategies to acquire new product technology (White, 2000). Generally, however, manufacturers are still heavily reliant on research institutes for new product technology (White and Liu, 2001). R&D departments in nearly all manufacturing firms are primarily devoted to quality control and assurance activities. Only a few firms have made substantial and productive investments in internal R&D capabilities that can help them develop new products and processes in-house.

More commonly, manufacturers choose to acquire new technology through two types of transactions with research institutes. Some research results are sold through an auction-like process, with research institutes trying to maximize the return to their technology (although they rarely have the internal skills to estimate the potential value of their research results). This process may be relatively open. One important vehicle for such transactions is the semiannual conference organized by SDA at which research institutes can publicize their research results as well as bargain with potential licensees. In other cases, a manufacturer will subcontract research to a research institute. The government has put pressure on research institutes to find such corporate customers in order to reduce their reliance on government support. In either case, while royalty payments were common in the late 1980s and into the 1990s, this has been largely replaced by flat payments to the research institute. The research institutes found that it was impossible to gain access to a manufacturer's sales and profits accounts, and sales-based royalties could be delayed for up to several years while a new product was in regulatory review, production facilities built, and bills collected.

Three factors perpetuate this pattern of organizationally separate loci for new product R&D and manufacturing. First are the bureaucratic boundaries, and these are overlaid by geographic boundaries; exchange of ownership rights across such boundaries is still problematic and politically charged.

Even within the same region and under the same line ministry, the existing skill base and resources of the manufacturing firms are a second factor perpetuating separation. During most of the decades since their founding, Chinese pharmaceutical manufacturing firms have had no mandate to be involved in R&D, and certainly did not harbor R&D skunk-works. Their managers were knowledgeable about manufacturing processes, and the firms were responsible for final process scale-up work. However, they were not involved in searching for new compounds, developing new synthetic processes or altering known ones, and other "knowledge-creating" activities that characterize R&D. In addition, the cost of developing a critical mass to undertake research internally is prohibitive for most manufacturers. Few of them have the excess funds to invest in research capacity whose eventual contribution to financial outcomes is uncertain at best. The importance of scientific expertise in developing new product and process know-how in this industry and the scarcity of labor with the requisite knowledge base serve as additional barriers to entry for the manufacturers; it is very difficult for these state-owned enterprises to recruit capable scientific personnel.

The third factor perpetuating the dis-integration of R&D and manufacturing has been an ample supply of research. As Table 1 shows, at least 73 research institutes contributed research to the 163 bulk compounds approved during 1985-94. This understates the total number of research institutes, since this number includes only those involved in approved new compounds. Of course, the number of research institutes in any given therapeutic category is much smaller, and the institutes do tend to specialize. Still, these numbers suggest that a manufacturer has a large number of potential sources of technology, especially since a manufacturer is relatively flexible in its ability to produce different types of compounds. Further, any manufacturer offering cash will have many willing partners since most of the research institutes are financially strapped.

Manufacturers do have a third choice besides make or buy; namely, they may pursue new product technology development jointly. As Table 2 shows, manufacturers in the major production regions (Beijing, Liaoning, Shanghai, Jiangsu, Shandong, Guangdong and Sichuan) have been involved in the development of 30-75% of new compounds they produce. For some firms, this may simply be a way of maintaining greater control over a research institute and the development activities on which it is relying for new products and future income. For other firms this may represent a learning experience, helping them increase their own internal R&D capabilities. From the basic data presented here, it is impossible to discern which of these motives is at work in any particular case. Nor is it possible to evaluate whether such joint activities are increasing or decreasing in frequency and importance. However, such relationships represent an alternative mode by which a manufacturer may obtain this complementary asset, and thus variation within the cross-functional network.

With reforms, some of the research institutes have also decided to manufacturer products that they develop. Many medical colleges, schools of pharmacology and hospitals have established their own production facilities. Two examples are China Pharmaceutical University in Nanjing (under SDA) and the Medical Biotechnology Research Institute in Beijing (under the Chinese Academy of Medical Sciences). For them, this functional diversification is a chance to shift excess personnel to revenue-generating activities. SDA, however, has begun to discourage such in-house manufacturing ventures by research institutes because their production scale is very low and not economical. These institutes do not have access to funds necessary to build large-scale production facilities, nor are they able to recruit personnel with manufacturing experience. While the research institute may be satisfied with relatively small sales volume, SDA would prefer that high-potential product technology go to manufacturers who already have sunk investments in production equipment and who are also in need of increasing revenues. Still, this diversification has been quite successful for some research institutes. For example, the Biological Products Research Institute under MPH is ranked 92nd among pharmaceutical producers with sales of RMB 108 million (US$13 million). Institutes that concentrate on biotechnology products for which economic production scale is much smaller than for synthetic chemical compounds have a better chance of being competitive.

Manufacturing and distribution

Under the command economy, manufacturers were required to transfer all of their production output to the government's distribution system. This geographically-based, three-tier distribution network was the link between the manufacturers and hospitals or other outlets (at that time, there were no retail outlets like drug stores, but some organizations operated their own clinics). At the top were five supra-regional distributors, and under them the second-tier distributors, usually two per province or municipality. Finally were the thousands of third-tier distributors ("stations") found at the county level.

New and existing products were pushed through the system by bureaucratic directives, from research to manufacturing through the distribution system to hospitals. Within this system, marketing and sales activities, which account for a large part of a pharmaceutical firm's costs in developed economies, were non-existent. Not surprisingly, at the beginning of the reform period pharmaceutical manufacturers did not undertake any sales or marketing activities, and their involvement in distribution was limited to transporting their products to centralized government warehouses.

SDA's monopoly on distribution that it inherited from MPH was officially dismantled in 1996, lagging by several years the de facto breakdown of the three-tier distribution system. Not only was it inefficient in matching supply to demand, the general problem of command economies resulting from information limitations, but it also added to final costs. Each tier exacted a 10-15% margin for handling a product, an important disadvantage as price-based competition increases. At the same time, centralized restrictions on who can sell to hospitals—formerly restricted to the SDA distribution companies of the lowest tier of the system, including the thousands of county-level stations—have been lifted. Now, provincial and municipal governments can issue distribution licenses to other firms, including manufacturers and private wholesalers, and these licenses permit them to sell directly to hospitals.

These changes, however, have not resulted in a general trend by either manufacturers or distributors to integrate by internalizing related capabilities (e.g., White and Liu, 2001). Most manufacturers still are only nominally if at all involved in sales, marketing and distribution activities to final outlets (hospitals and retail outlets). Even in the late 1990s, for example, one of the largest manufacturers with 10,000 employees and dominant market shares in several categories of antibiotics had only 40 employees involved in sales and marketing activities; a much smaller firm with 500 employees (but still in the top 500 in terms of production and sales), only 9. Neither firm undertakes detailing activities to doctors, which can represent one-third or more of the employees in Japanese pharmaceutical firms. Instead, they continue to rely on outside organizations to market, take orders for, and distribute their products to hospitals. This pattern is common for both commodity-like pharmaceuticals produced by several or more manufacturers (like many types of antibiotics, for example), and for more differentiated products with unique characteristics and produced by one or very few manufacturers.

Instead of undertaking these activities, now a manufacturer usually has sales and distribution agreements with one or more wholesalers for each geographic market it serves. The manufacturer gives the distributor a price, and the distributor then negotiates with a local station (part of SPAC's former distribution monopoly) in regions with many but relatively small hospitals and clinics, or directly with in-house pharmacies in the case of major hospitals.

As already discussed, direct marketing to doctors ("detailing"), which is the basic marketing activity in developed countries complemented by advertising, is not yet the key to increasing sales in China. Instead, price and the margin are the primary criteria. The most important target audience is the director of a hospital's in-house pharmacy, who makes all purchase decisions. He is primarily interested in products with high prices and large absolute margins, typical of most foreign products, or those with large discounts to maximum allowed price for those drugs reimbursed by the government (Huttin, 1994). In either case, he is usually assured a kickback for his favor. Further, since "sales" are in practice actually consignment, the hospital pharmacy only pays for the products after they are sold to patients. Hence, inventory costs do not act as an incentive for the director to refuse to stock products with high prices or profit margins.

Not all distributors, however, are created equal. With reforms, three types of distributors have emerged. One is the local station which under the command economy monopolized contact with local hospitals' in-house pharmacies. They are now part of the commercial ventures of the former SPAC bureau that were separated from the regulatory and promotion activities now undertaken by SDA. These stations are now expected to generate their own revenues, and they are treated as profit centers. A second type of distributor are new entrants, usually small, private and local wholesalers who have agreements with manufacturers to sell in a particular geographic market. Some manufacturers have also obtained distribution licenses, but usually limited to the region in which they are headquartered.

Third are the diversifying national distribution organizations, originally state-operated with core businesses in other product categories but diversifying into pharmaceutical and health care product distribution. They are best characterized as federations of regional organizations with dual reporting relationships, to both the operational "headquarters" at the central government level as well as their local governments. The horizontal relationships among the regional "branches" facilitated by a central headquarters could make these organizations the precursors of firms with truly national scope, currently lacking in most of China's industries.

While the stations no longer monopolize contact with hospitals, they still have informal relationships with other parts of the former SPAC bureaucracy that control the licensing of distributors. This relationship makes a station distributor very powerful relative to the other, mostly small and private, distributors in a particular region. Further, as the stations are part of the local government bureaucracy, they tend to protect local interests. Therefore, they rarely grant local distribution licenses to out-of-town organizations, and hospitals are allowed ("encouraged") to buy only from locally-licensed distributors: in other words, the former SPAC stations or the distributors they have licensed.

The relationship among the local bureaus, locally licensed distributors, and local hospitals and retail outlets leads to regional protectionism. This protectionism affects the manufacturers' decisions regarding sales and distribution in two ways. First, there are no single distributors who have the multiple regional distribution licenses which would be necessary to create a national distribution company. Even the diversifying national distribution companies have only just begun to integrate their activities; their relative independence from each other hinders development and implementation of a coordinated national strategy. Hence, a manufacturer must rely on a different distributor for each region. Second, the manufacturer itself is equally unlikely to obtain a distribution license for any region besides that in which it is headquartered. As already described, any single manufacturers' operations traditionally were limited to a single site or city, and never more than one province or province-level municipality (like Beijing or Shanghai). They face the same regional protectionism that distributors face in other regions outside their headquartered region.

International marketing and sales, however, present an exception. Just as SPAC's monopoly on domestic distribution has been ended, so has its monopoly on exports. While it also retains indirect control through its power to grant and rescind export licenses, the firms ironically do not face the same problems of protectionism overseas that they face domestically. To sell overseas, some manufacturers have obtained the necessary export licenses and have begun to build up international sales departments. This is especially true for firms that had previously sold their products overseas through the SPAC export company. One Beijing firm, for example, has aggressively recruited university graduates with English abilities to increase its overseas sales department, while none have been assigned to domestic sales. On the other hand, firms which have no previous experience with exports or with relatively little in export sales continue to rely on specialized export representatives, often a SPAC or other government-owned export company, but increasingly private agents.

As in the case of R&D, manufacturers face several important constraints in their choice to undertake sales and distribution activities or not. Lack of experience in marketing activities and lack of managerial and financial resources to establish and maintain a national sales network are two barriers. Considering the geographic size of the Chinese market, it may indeed be uneconomical for an individual firm to establish its own national network. Since there are many distributors to choose from in any given regional market (Table 1), competition among distributors may improve the manufacturer's bargaining position relative to a distributor. Equally if not more important is the regional protectionism that has developed around local distribution activities. Together, these factors help maintain the organizational separation of manufacturing and sales activities which have characterized the pharmaceutical industry since the command era.

Within this general trend, however, there are exceptions that may become more common as reforms progress. Already variations from the hand-off characterizing the manufacturer-distributor relationship under the command era and well into the transition period are appearing. First, some manufacturers are investing in their own marketing, although less so in physical distribution. As firms begin to produce a larger number of unique products, especially those with higher margins, they stand to gain more from economies of scale in marketing efforts. This might serve as incentive for them to channel more resources to these activities and to undertake these activities themselves rather than relying on outside organizations. Second, while most mergers have been between manufacturers (for the reasons discussed in the following section), there are examples of manufacturers being merged with or acquired by distribution companies. These distributors are diversifying into pharmaceuticals and, as one part of their strategy, are acquiring drug-producing organizations.

INTRA-FUNCTIONAL NETWORKS

While the preceding section described the dominant structure and dynamics of the cross-functional networks in China's pharmaceutical industry, this section examines the intra-functional networks within R&D and manufacturing that give rise to those complementary assets. To analyze the structure of the R&D network, we draw on a unique database of interorganizational collaboration leading to R&D outputs. For the description of the manufacturing network, we draw on extensive industry reports and regulatory data. For both networks, we relate changes in the network to related policy initiatives and the competitive environment, and the cumulative impact on the incentive structure facing actors in these organizations.

R&D

As already discussed, under central planning the functionally specialized organizations such as research institutes were controlled by the relevant industrial bureau, which in the pharmaceutical industry was SPAC until the major reforms in the late 1990s. SPAC (or its predecessors) oversaw the funding of research projects, and also dictated any interorganizational collaborative activities. Over the course of the transition period, especially since the late 1980s, however, researchers have had much greater freedom to initiate projects and undertake collaborative work across organizational boundaries. At the same time, researchers came to be rewarded more and more by their organizations for bringing in grants and publishing academic articles. Interorganizational collaboration, therefore, has become one possible means for researchers to propose and undertake more competitive research.

To investigate the structure and evolution of the R&D network that generates the codified scientific and technical knowledge in China's pharmaceutical industry, we have compiled a database of all abstracts included in the Chinese Pharmaceutical Abstracts (*Zhongguo Yaoxue Wenzhai*) for the years 1983-1996. This source provided information including journal, year, author and affiliation, and topical category for 157,735 abstracts over the 14 years. Up to three authors and their affiliations were listed. Altogether, the database allows us to identify 148,039 individuals, 55,314 organizations or sub-units, and 1,735 journals or other publications covering all scientific and technical areas related to the pharmaceutical industry. Table 4 presents the number of new individuals, organizations or sub-units, and journals appearing in the database each year.

Next, each organization or sub-unit was assigned a unique ID code and dummy variables to indicate its regional location (31 provinces and province-level municipalities) and organizational type (such as hospital, research institute, university, military unit, etc.). Dummy variables were also created to categorize each abstract by the number of authors, organizations, and regions involved. Data from this abstract database were aggregated by organization, creating a second database of organizations and summary variables, such as number of publications by year.

Although future network analyses at the organizational level will rely on this second database, preliminary analyses of the abstract database suggest important trends in interorganizational collaboration within China's pharmaceutical R&D network. First, there is a clear and consistent trend over the entire period towards greater interorganizational collaboration (Figure 3). Both the number and percentage of all abstracts involving 2 or more organizations has been increasing, representing approximately 22% of all papers in 1996. This same figure suggests that there may have been at least two periods, 1986-87 and 1993-94, in which institutional changes may have led to a change in collaborative behavior. Of course, we must also investigate whether the substantial increases in numbers of journals over those two periods, or other methodological causes, account for these apparent changes.

Second, the data suggests important changes in the types of organizations involved in R&D (Figure 4). Over the period, hospitals have come to play a more important role in generating publications. In addition to any incentives for individual doctors to publish, they also control access to patients, a vital resource as clinical data becomes important for acquiring regulatory approval to market a new drug. In contrast, there has been a steep decline in the share of publications by both dedicated research institutes and firms, and somewhat less of a decline for tertiary institutes (universities and colleges). This suggests that the relative importance of China's research institutes may be declining as other types of organizations increase their research activity. It also implies that manufacturers as a group may be becoming less important in R&D over time, in spite of the government's efforts to promote R&D activities in firms.

The data also suggest important trends in collaboration both between individuals (Figure 5) as well as across regional boundaries (Figure 6). While the percentage of 2-authored papers has held steady over the period, single-authored papers as a percentage of all papers peaked in the mid-1980s at nearly 50% but, by 1996, had dropped to approximately 30%. Papers with 3 or more authors, on the other hand, increased proportionally over the same period. Over the same period, there is a dramatic increase in the number of inter-regional collaborations, although still only a small percentage of total publications.

We examined the inter-regional ties by summing the total collaborations between each pair of regions (Table 5). We find that the regions with both the largest and smallest numbers of interorganizational ties also have the largest percentages of cross-regional ties. Further, Beijing is the primary partner region of all but 4 regions, clearly demonstrating its role as a national research "hub". However, Shanghai and Jiangsu are also major hubs (or arguably part of a single regional hub that would also include Zhejiang), as well as Guangdong and Sichuan. An alternative approach to this same regional data could identify clusters, since there are clear groupings of regions such as Shanghai-Jiangsu-Zhejiang and Jilin-Liaoning-Heilongjiang, among others.

Manufacturing

During the command era, a manufacturing firm's decision to install a line to produce a new compound was actually made and funded by MPH. Just as MPH directed new technology to the manufacturing firms, so did it direct the necessary human and financial resources to implement the process. For important, basic drugs like penicillin and other antibiotics, there was often gross overproduction. MPH designated not just one but many manufacturers to produce such drugs. MPH's concern was with assuring supply, not economic viability of an individual firm or financial return to investment in a production line. The firms also had no incentive to argue with production being directed their way, as long as MPH also provided the funds to implement it. None of their income depended on revenues or profits which in a "market" economy would be driven down by drastic over-supply. Further, there was no consideration of outsourcing production, nor incentives to rationalize production by discontinuing production or merging to achieve economies of scale. If anything, manufacturers were inclined to vertically integrate to maintain control over the supply of inputs on which their achieving production targets depended.

As already described, with economic reforms the manufacturers have faced a new need to be concerned with supply and demand conditions, as well as productivity. They now hope to increase revenues and break even, "at least make enough to pay salaries," as the general manager at one manufacturer commented. Thus, they are more aware of a new product's price and potential profitability, which are affected by both supply and demand conditions and the government-regulated price (in the case of drugs which are on the government's reimbursement list).

Perhaps not surprisingly, manufacturers still overwhelmingly choose to internalize production of active ingredients. First, most have excess personnel that are effectively fixed costs in the short- to medium term, and the firms are anxious to devote them to revenue-enhancing activities. Second, the government gives tax breaks for sales of new compounds and also provides subsidies or soft loans for firms to purchase equipment to produce new compounds. Third, firms acquire new technology in order to implement it in-house. They are the users of such new technology, not the source, and do not sub-license technology to other manufacturers.

The result is a situation in which the manufacturers' behavior and supply and demand imbalances surprisingly resemble the industry under the command economy and MPH's direction. Most manufacturers produce at an uneconomical scale, artificially supported by tax breaks and subsidies that let them discount initial capital investment. Overproduction is common, especially for products on the government insurance reimbursement list. Since many of the compounds being produced are off-patent ("generics", in the US industry terminology), many research institutes can "develop" the technology for a given compound and subsequently supply it to many manufacturers. This leads to redundancy in products and over-production that drive down individual firm revenues and industry profits. For example, in the 1990s ten manufacturing and marketing licenses were approved for the same antibiotic compound, each application being made by a separate coalition of research institutes and manufacturers. While the Chinese government does not directly pursue a policy of technology diffusion to achieve social purposes (except in a few rare cases, such as hepatitis-B), wide diffusion of new compound technology is still common and a reason behind the dramatic oversupply of certain drugs.

Since the early 1990s, the industry has begun to see some consolidation, not through bankruptcies but through mergers among manufacturers. Most of these mergers are unrelated to firm-level strategies for obtaining complementary assets to create a new technological system leading to new products. Rather, SDA has recognized the industry-level economic inefficiency of having so many relatively small manufacturers with overlapping output. Many manufacturers are not financially viable, and lack of production economies of scale is acknowledged as a contributing factor. However, closing loss-making operations through bankruptcy has not been a politically popular alternative, although since the late 1990s this has become increasingly common as the central governments pursues a policy of "keeping the large and letting go of the small."

Whenever possible, SDA and local governments are "assisting" manufacturers operating at a loss to find a partner, usually another manufacturing firm which is profitable and can absorb the smaller firm's losses. Further, as already discussed, these consolidations invariably occur within a single geographic region and within the same administrative and bureaucratic "turf."

Acquisitions by non-pharmaceutical industry firms, such as private enterprises who have made money through activities unrelated to health care such as real estate development, have been very rare. Local governments directly responsible for the firms are loath to accept that a manufacturer has almost no or even negative value as an on-going concern. Methods of valuing a business, common in developed market economies, are not yet widely understood nor accepted in China. Neither is a suitor's offer to assume an operation's debt very attractive to a local government, since it sees no revenue inflow from the sale. Political leaders are especially sensitive to any criticism that they are "giving away" state assets. Even when a private firm is able to purchase a state-owned firm, its ability to cut costs, especially by shedding employees, is severely restricted. Prior managers argue, not without justification, that if they were also given this option, they too could improve the financial performance of the firm.

A merger with another state-owned pharmaceutical manufacturer, however, overcomes many of the accounting and political problems confronted in a sale to a private firm. After such mergers, either the operations can be improved or redundant production, personnel and other costs can be cut as necessary. This avoids the appearance of an entire firm going bankrupt while enabling loss-making operations to be shut down. In this process, the loss-making firms are relatively passive. The larger and financially successful firms are, understandably, not happy to be saddled with dead weight. However, the mergers are driven more by SDA's desire to reduce the number of loss-making enterprises than by any concern with strategic fit. While the long-term impact on productivity is not clear, SDA's policy will by design lead to a smoothing of the variance in economic performance among firms in the industry.

NETWORKS AND INCENTIVES IN TRANSITION

The case of the pharmaceutical industry is illustrative of the challenge facing many of China's state-controlled industries; namely, what reforms will lead to a more efficient and effective product innovation system. We have presented a description of the process that has taken place in this industry, focusing on changes in the way that functional complementary assets are created and combined. In this regard, the major impact of transition-era reforms has been a fundamental change in incentive structure; i.e., the onus of responsibility for acquiring complementary assets is increasingly falling on the research institutes, manufacturers and distributors themselves. An increasing portion of research institutes' budgets depends on their bringing in funds from corporate clients, either by selling their research results, undertaking contract research, or training a manufacturer's employees. Similarly, manufacturers must find their own sources of new product technology, either from research institutes or through their own internal R&D activities. The manufacturers must also find ways to place their products in hospital pharmacies and retail outlets domestically, as well as sell in overseas markets. Finally, distributors formerly comprising the SPAC-coordinated national distribution system are now responsible for their own accounts, and they are being joined by newly established wholesalers competing for representation of manufacturers' products and sales to hospital pharmacies, clinics and retail shops.

This change in incentive structure has, in turn, had a major impact on the structure and dynamics underlying the cross-functional and intra-functional networks linking activities and organizations in this industry. While the cross-functional networks are still dominated by functionally specialized organizations, the coordinating mechanism has changed fundamentally. Under the command era, SPAC or its predecessors oversaw resource creation decisions within functionally specialized research institutes, manufacturers and distributors (Figure 1a). It also coordinated the interfunctional, interorganizational transfers of these resources. Now, after nearly twenty years of economic and enterprise reforms, complementary assets are still primarily transferred between functionally specialized organizations. However, coordination mechanisms for these transfers have shifted from bureaucratic fiat to bilateral negotiation between the two organizations (Figure 1b).

Although still the exceptions, some functionally specialized organizations have responded to the change in incentive structure by diversifying into other functional activities; for example, a research institute undertaking manufacturing, manufacturers becoming involved in R&D and marketing and sales, or a wholesaler integrating into manufacturing. For some compounds, research institutes and manufacturers are undertaking joint development. With few exceptions (like the merger of some manufacturers with wholesalers), these organizations are diversifying into new activities through internal development of new activities, not mergers and acquisitions. There are no cases, for example, in which a research institute and manufacturer have merged. Furthermore, none of the organizations yet exhibit the full functional integration of major pharmaceutical firms in developed countries (Figure 2). Indeed, industrial laboratories in the large US manufacturing firms have evolved from a very different set of initial conditions, and we doubt whether the Chinese manufacturers could or should consider those firms as a development model.

Our description of the intra-functional networks in R&D and manufacturing also illustrate the very different paths that different functional networks have taken. In the case of R&D, we find a dramatic increase in collaboration across organizational and geographic boundaries over the reform period. This may, however, be the case only for basic and early-stage applied research. Other studies (e.g., Liu and White, 2001) have shown that collaborative activity has actually decreased as research moves downstream. In other words, as the commercial stakes become higher, organizations are less willing to collaborate.

Still, the contrast with trends in the manufacturing functional networks is clear. Pharmaceutical manufacturers continue to favor vertical integration (within manufacturing activities); there has been no perceptible increase in outsourcing or subcontracting. There have also been numerous mergers among manufacturers, both self-initiated and state-dictated. Of course, this may be the result of this industry being a process rather than assembly-based industry. While components may be easily outsourced in electronics, for example, it is nearly impossible to outsource sub-activities in a continuous process, such as in the pharmaceutical and petrochemical industries.

Unintended consequences

The choices managers in these organizations are making in response to new incentives, however, are still strongly influenced by the initial starting conditions; namely, an industrial structure comprised of functionally specialized organizations, and managers responsible for meeting, not setting, operational and strategic goals. The gap between this legacy and the stated objective of a competitive, market-based economy, as well as unintended consequences of reform policies resulting from this gap, represent the main challenges facing successful reform. The major shortcoming of reforms to date has been the inability to create an incentive structure that encourages efficient use of resources by organizations still under ownership and subject to intervention by the state.

The problems of the state-owned manufacturing enterprises (SOEs) in this regard have received the most attention (Broadman, 1995; World Bank, 1997; Steinfeld, 1998). The discussion of the pharmaceutical industry, however, shows that the inefficient use of resources is endemic to other functional organizations. In industries like pharmaceuticals that have been dominated by a state industrial bureau, all of the functional organizations comprising the innovation network—the research institutes, manufacturers and wholesalers—operate within an incentive structure and bureaucratic environment which is both deeply embedded and often at odds with the government's stated objectives for reforms.

For example, the government has implemented policies that create an incentive for research institutes to increase their revenues. The government's intention was for the research institutes to find buyers and underwriters of their research, both to take some of the funding burden off the government as well as to channel research effort towards downstream applications. However, many research institutes (including universities and hospitals as well as research institutes per se) have also begun to undertake manufacturing, allocating to production activities funds and personnel originally assigned to the institute for research. They generally do not have the funds necessary to construct production facilities at economically efficient scale, nor can they obtain subsidies or commercial loans for this purpose. Still, they are able to discount the cost of the capital and personnel they do use; salaries for existing personnel, for example, are guaranteed by the government, and research funds are easily diverted to manufacturing ventures (albeit relatively small-scale). For these institutes, then, gross revenues are reduced only by the cost of raw material inputs, not by the other costs of manufacturing, such as labor and capital. While certainly not efficient if true costs were included, from the institute's point of view these revenues are attractive positive in-flows. Thus, while the policy to encourage institutes to become revenue-generating is "succeeding", the result has been a less efficient use of some resources.

Bureaucratic barriers leading to turf protection also inhibit the re-configuring of state resources into more efficient combinations. Organizational affiliation is defined along one dimension based on regulatory and, in some cases, budgetary responsibility (e.g., remnants of the industrial bureaus) and another based on geographic jurisdiction (provincial, county and municipal governments). These affiliations define political turf and can act as severe barriers to mergers or consolidation both intra-functionally, as between manufacturers, or inter-functionally, between research institutes and manufacturers or between manufacturers and wholesalers. The direct result of these barriers is that there are few mergers between organizations affiliated with different bureaus or located in different geographic administrative regions. If they interact at all, organizations do so across these barriers without a change in ownership structure. Accordingly, organizations have fewer options for increasing functional scale or scope, limiting the prospects for increasing overall industry resource efficiency.

Areas for further research

Our description of changes in this industry's product innovation system based on the structure and dynamics of cross-functional and intra-functional networks and organization-level incentive structures is only a beginning to understanding cross-level interactions in a transitional context. Future research should do this systematically. For example, to understand changes in R&D collaborative behavior, it is necessary to relate the policy, market and network environments on one hand and organizational-level data on the other. This includes identifying changes in network structure over time, as well as comparing the structure and changes in the different functional networks (R&D,

manufacturing, distribution). Analyses at this level could answer questions about changes in network density, clusters of organizations and highly central organizations, and the geographic distribution of network linkages. This would also allow comparisons across these different networks that, our initial study has suggested, may exhibit very different evolutionary patterns.

Results from network-level analyses should also be linked to organization-level behavior and outcomes. This would allow us to answer questions concerning organizational strategy and performance, such as: Are more innovative manufacturers linked to research organizations that are more centrally located in the "scientific knowledge" network? Does this relationship differ depending on whether we consider new product or productivity measures of innovation outcomes? Do manufacturers who are linked to such research organizations invest more or less in R&D or other capabilities? Are such linkages used to complement or substitute for internal R&D activities?

By focusing on the organization of the functional activities of the innovation network, we have only begun to address the larger issue of firms' make-buy-or-ally behaviors under the emerging economic environment. Further research could use the same approach as this study to compare the procurement behavior of firms before and during the transition period. As in the case of acquiring functional outputs, with economic and enterprise reforms Chinese firms have more discretion to choose how to procure manufacturing inputs. Which inputs are being procured on the market, through hybrid relationships, or by internalization? What factors seem to be most important in the choice of procurement strategy? Although inherently descriptive rather than hypothesis-testing, such research would further understanding of the context and dynamics driving Chinese firm behavior and industry structure.

Another prospect for further research would be to compare the changes in innovation networks across different industries that were all organized along the Soviet model under the command economy. For example, in other industries like automobiles and computers, the relevant government industrial bureaus have merged leading research institutes and manufacturers, unlike the case of the pharmaceutical industry. Under what conditions might the government be advised to encourage mergers or internal development to bring about functionally diversified organizations? Under what conditions would a structure comprised of functionally-specialized and independent organizations be preferable? These are important policy and managerial issues since the governments and organizations' choices are likely to impact organizational, industrial and national economic performance and competitiveness.

In addition to the contribution to the broader literature on network evolution and organizational strategy, answering such questions would also shed light on the dynamics of collaboration among Chinese organizations related to innovative activity. In this regard, Suttmeier (1997) has identified shortcomings in the Chinese science and technology system related to interorganzational collaboration, although he also expresses some guarded optimism. Have Chinese organizations, with their long history of involvement in cross-functional interorganizational relationships, have developed mechanisms that support or smooth such relationships. Work on the role of guanxi (connections) in Chinese business (King, 1996; Whitcomb & Li, 1996; Xin & Pearce, 1996; Peng & Heath, 1996) could be extended in this direction. Results could be compared with findings from prior research in the management of technology and new product development in developed economies, which underlines the exceptional difficulty of successfully managing tasks that are both inter-functional and inter-organizational.

There may also be important context-specific characteristics for collaboration between Chinese organizations. For example, research in other contexts has emphasized the importance of trust and reciprocity on collaborative activity. It remains an empirical question how Chinese organizations, embedded in a "low-trust society" (Fukuyama, 1995), use and participate in networks to achieve innovation objectives.

CONCLUSIONS

In this paper we have attempted to reconcile a seeming paradox of China's transition period; namely, that the overall structure of the innovation network in the pharmaceutical industry has persisted from the command era through the current transition period. Interorganizational relationships link specialized research institutes, manufacturers and distributors to bring to market most of China's new drugs. Our analysis, however, has shown that the incentive structure and dynamics underlying observed structure of cross-functional and intra-functional networks comprising the product innovation system have changed dramatically. The system has evolved from centrally coordinated to self-organizing in response to the new set of incentives and regulatory policies that reforms have introduced.

We have also shown the sources of emerging variation within these cross-functional and intra-functional networks. Some of the functionally specialized organizations are diversifying into other functional areas; research institutes into manufacturing, manufacturers into R&D and marketing, wholesalers into manufacturing. We find increased collaboration across organizational boundaries within the intra-functional R&D

network, in stark contrast to the lack of interorganizational relationships within the manufacturing intra-functional network (except for mergers among manufacturers).

A more general intention of this descriptive study was to show how network and incentive structure concepts could lead to a more insightful analysis of the strategies and system structure and, in turn, generate questions for further research into organizational and system-level implications of these changes. We have shown the importance of understanding the process and implications of the interaction between interorganizational networks and the incentive structure surrounding actors and defined by both the policy and competitive environments. Future research in transition contexts should address related evolutionary phenomena at both the organizational and network levels, as well as test hypotheses suggested by institutional and network theories to explain these evolutionary patterns, organizational strategies, and performance implications.

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TABLE 1

Organizations and outputs of China's pharmaceutical innovation network

	Compounds[1]		*Organizations*		
Region	Bulk	Formulations	Research organizations[2]	Manufacturers[2]	Distributors[3]
CHINA	163	376	73	206	3963
Beijing	28	53	23	13	13
Tianjin	10	50	3	7	153
Hebei	7	17	0	3	231
Shanxi	8	15	2	6	15
Liaoning	27	58	7	18	142
Jilin	5	16	0	4	253
Heilongjiang	6	21	0	5	269
Shanghai	29	67	7	17	119
Jiangsu	33	62	5	26	198
Zhejiang	20	49	2	14	na
Anhui	1	7	0	1	581
Fujian	4	8	1	4	17
Jiangxi	5	12	1	4	na
Shangdong	23	34	5	18	na
Henan	7	15	4	7	212
Hubei	10	20	2	5	109
Hunan	8	12	0	7	181
Guangdong	25	61	4	16	43
Guanxi	2	10	0	2	74
Hainan	3	10	1	2	34
Sichuan	18	31	3	12	219
Guizhou	1	1	0	1	52
Yunnan	5	7	1	3	161
Tibet	0	0	0	0	na
Shaanxi	6	20	1	4	523
Gansu	1	3	1	0	208
Qinghai	1	2	0	1	45
Ningxia	0	2	0	0	30
Xinjiang	2	4	0	2	81
Inner Mongolia	4	5	0	4	na

Sources: Ministry of Public Health approval records, *Pharmaceutical Industry Yearbooks*.

(1) Number of unique bulk compounds or formulations produced in each region (one compound may be produced in more than one region) approved for sale 1985-94.

(2) Research or manufacturing organizations involved in both bulk and formulation production of new compounds approved for sale 1985-94.

(3) Private and state-owned distributors maintaining independent accounts as of 1993.

TABLE 2

Regional variation in innovative activities (R&D, production)

Region	Bulk compounds developed	Bulk compounds produced	Compounds developed/ produced	Manufacturer involved in development
Beijing	42	28	150%	29%
Tianjin	16	10	160%	40%
Hebei	5	7	71%	86%
Shanxi	6	8	75%	25%
Liaoning	23	27	85%	63%
Jilin	4	5	80%	80%
Heilongjiang	6	6	100%	100%
Shanghai	38	29	131%	69%
Jiangsu	25	33	76%	64%
Zhejiang	15	20	75%	50%
Anhui	1	1	100%	100%
Fujian	4	4	100%	0%
Jiangxi	2	5	40%	20%
Shangdong	17	23	74%	43%
Henan	5	7	71%	29%
Hubei	10	10	100%	10%
Hunan	3	8	38%	38%
Guangdong	22	25	88%	76%
Guanxi	2	2	100%	100%
Hainan	2	3	67%	33%
Sichuan	20	18	111%	61%
Guizhou	1	1	100%	100%
Yunnan	1	5	20%	20%
Tibet	0	0	-	-
Shaanxi	6	6	100%	100%
Gansu	1	1	100%	100%
Qinghai	0	1	0%	0%
Ningxia	0	0	-	-
Xinjiang	2	2	100%	100%
Inner Mongolia	2	4	50%	0%

Sources: Ministry of Public Health, *Pharmaceutical Industry Yearbooks.*

(1)Bulk active ingredients approved for sale 1985-94.

TABLE 3

Top 10 domestic manufacturers and their research partnerships [1]

Sales rank	Profit rank	Manufacturer	Location	Ownership or oversight	New products [2]	Partners [3]	Location
1	1	999 Nanfang	Guangdong	People's Liberation Army	1	None	-
2	3	Baiyunshan	Guangdong	Ministry of Agriculture	1	Chinese Medicine Research Center of Chinese Academy of Chinese Medicine (CACM)	Beijing
3	2	North China	Hebei	SPAC	2	Sichuan Antibiotic Industrial Research Center	Sichuan
4	5	Xinhua	Shandong	SPAC	3	None	-
5	6	Northeast China	Liaoning	SPAC	7	Pharmaceutical Research Center of Chinese Academy of Medical Sciences (CAMS)	Beijing
6	7	Harbin	Heilongjiang	SPAC	1	None	-
7	12	Shanghai No.2	Shanghai	SPAC	5	Radiology Research Center of People's Liberation Army Institute of Medicine	Beijing
8	21	Qilu	Shangdong	SPAC	5	Shandong Medical University, China University of Pharmacy, Shangdong Industrial Pharmaceutical Research Center, Pharmaceutical Research Center of Chinese Academy of Medical Sciences (CAMS)	Shandong, Zhejiang, Shandong, Beijing
9	8	Lukang	Shandong	SPAC	1	Shanghai Pharmaceutical Industrial Research Center	Shanghai
10	11	Hecheng	Sichuan	SPAC	4	Sichuan Antibiotic Industrial Research Center, Beijing Sida Biotechnology Research Center, Liaoning Dadong City Pharmaceutical Research Center	Sichuan, Beijing, Sichuan, Guangdong

(1)Three foreign firms were in the top 10 in both sales and profits: Xian-Janssen, Tianjian Smith-Kline and Shanghai Squibb. They have no domestic research partners, nor do they produce active ingredients in China (final formulation only in China).

(2)All of the firm's "western" pharmaceutical compounds (bulk form) approved for sale 1985-94.
(3)Only one of the partnerships (Qilu and China University of Pharmacy) was for more than one compound; some compounds were developed in-house by the manufacturer, according to Ministry of Public Health approval records.

TABLE 4

Authors, organizations and journals in China's pharmaceutical R&D network

Year	New authors	(YOY % increase)	New orgs.	(YOY % increase)	New journals	(YOY % increase)
1983	1,702		473		11	
1984	7,737	455%	2,384	504%	157	1427%
1985	7,675	81%	2,299	80%	97	58%
1986	9,156	54%	3,264	63%	74	28%
1987	8,628	33%	3,748	45%	108	32%
1988	8,547	24%	3,344	27%	121	27%
1989	8,589	20%	3,268	21%	107	19%
1990	9,780	19%	3,795	20%	69	10%
1991	7,755	13%	2,955	13%	61	8%
1992	8,686	12%	3,225	13%	61	8%
1993	11,852	15%	4,515	16%	274	32%
1994	18,933	21%	6,921	21%	206	18%
1995	18,929	17%	7,012	17%	152	11%
1996	20,070	16%	8,111	17%	237	16%
Total	**148,039**		**55,314**		**1,735**	

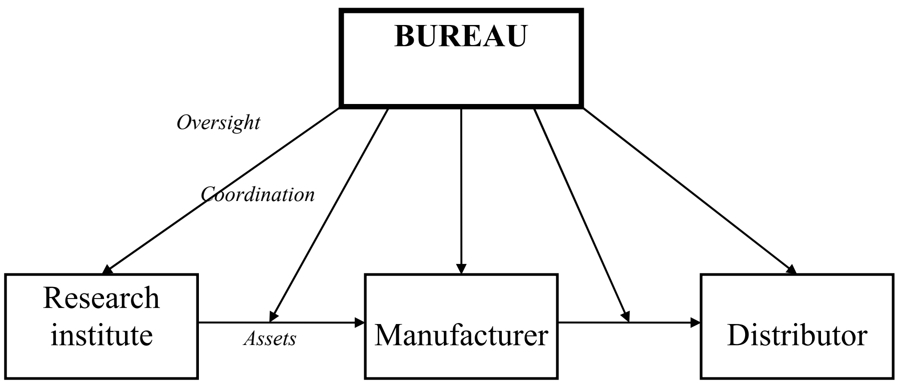
TABLE 5

Inter-regional collaboration in pharmaceutical-related scientific articles

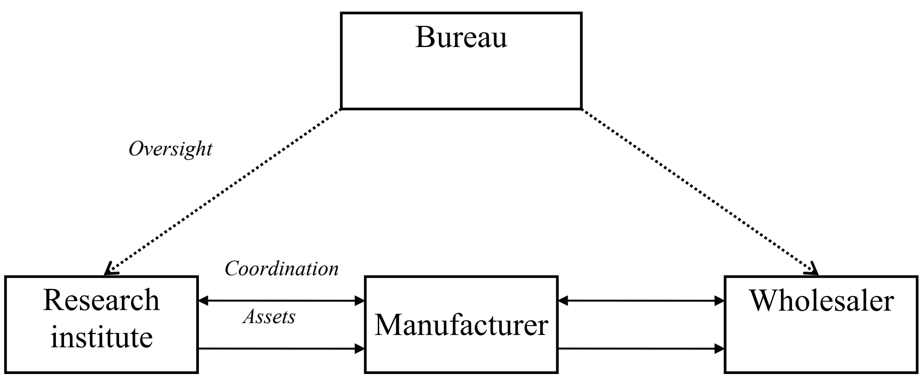
Region	All interorg. ties	%cross-regional	Main partner region	Secondary partner regions
Beijing	3,361	66%	Jiangsu	Shanghai, Liaoning, Hubei
Tianjin	416	44%	Beijing	Hebei, Shanxi, Henan
Hebei	750	31%	Beijing	Tianjin, Jilin, Henan
Shanxi	619	28%	Beijing	Tianjin, Jiangsu, Shandong
Liaoning	950	45%	Beijing	Jilin, Heilongjiang, Shanghai
Jilin	905	36%	Beijing	Liaoning, Heilongjiang, Shandong
Heilongjiang	924	24%	Liaoning	Beijing, Jilin, Shanghai
Shanghai	1,658	45%	Beijing	Jiangsu, Guangdong, Zhejiang
Jiangsu	1,526	42%	Beijing	Jiangsu, Zhejiang, Henan
Zhejiang	779	31%	Beijing	Shanghai, Jiangsu, Shandong
Anhui	499	34%	Beijing	Shanghai, Jiangsu, Guangdong
Fujian	557	31%	Beijing	Shanghai, Jiangsu, Guangdong
Jiangxi	388	43%	Beijing	Guangdong, Shanghai, Henan
Shandong	1,504	20%	Beijing	Shanghai, Jiangsu, Hubei
Henan	1,035	29%	Beijing	Shanghai, Jiangsu, Shandong
Hubei	831	39%	Beijing	Guangdong, Shanghai, Jiangsu
Hunan	419	41%	Beijing	Guangdong, Shanghai, Hubei
Guangdong	855	53%	Beijing	Shanghai, Hubei, Jiangxi
Guangxi	309	37%	Beijing	Guangdong, Jiangsu, Shanghai
Hainan	49	78%	Beijing	Guangdong, Hubei, Yunnan
Sichuan	728	40%	Beijing	Yunnan, Guizhou, Shaanxi
Guizhou	204	43%	Beijing	Sichuan, Chongqing, Jiangsu
Yunnan	272	44%	Beijing	Sichuan, Shanghai, Zhejiang
Tibet	30	83%	Sichuan	Beijing, Sichuan, Shaanxi
Shaanxi	703	46%	Beijing	Gansu, Shanghai, Guangdong
Gansu	418	45%	Beijing	Xinjiang, Guangdong, Zhejiang
Qinghai	75	36%	Beijing	Jiangsu
Ningxia	68	54%	Beijing	Liaoning, Shanghai
Xinjiang	181	46%	Beijing	Gansu, Shanghai, Jiangsu
Inner Mongolia	228	33%	Beijing	Liaoning, Jilin, Heilongjiang
Chongqing	233	59%	Sichuan	Beijing, Shanghai, Guangdong
All regions	***21,474***	***42%***		

FIGURE 1
Interorganizational relationships in the command and transition periods

(a) Command era structure



(b) Transition period structure



From the centralized command-and-control structure under the command era (a), economic reforms have reduced the role of the industrial bureaus; functionally specialized organizations are responsible for coordinating complementary asset transfers (b).

FIGURE 2

Alternative structures for cross-functional networks: functional integration vs. dis-integration

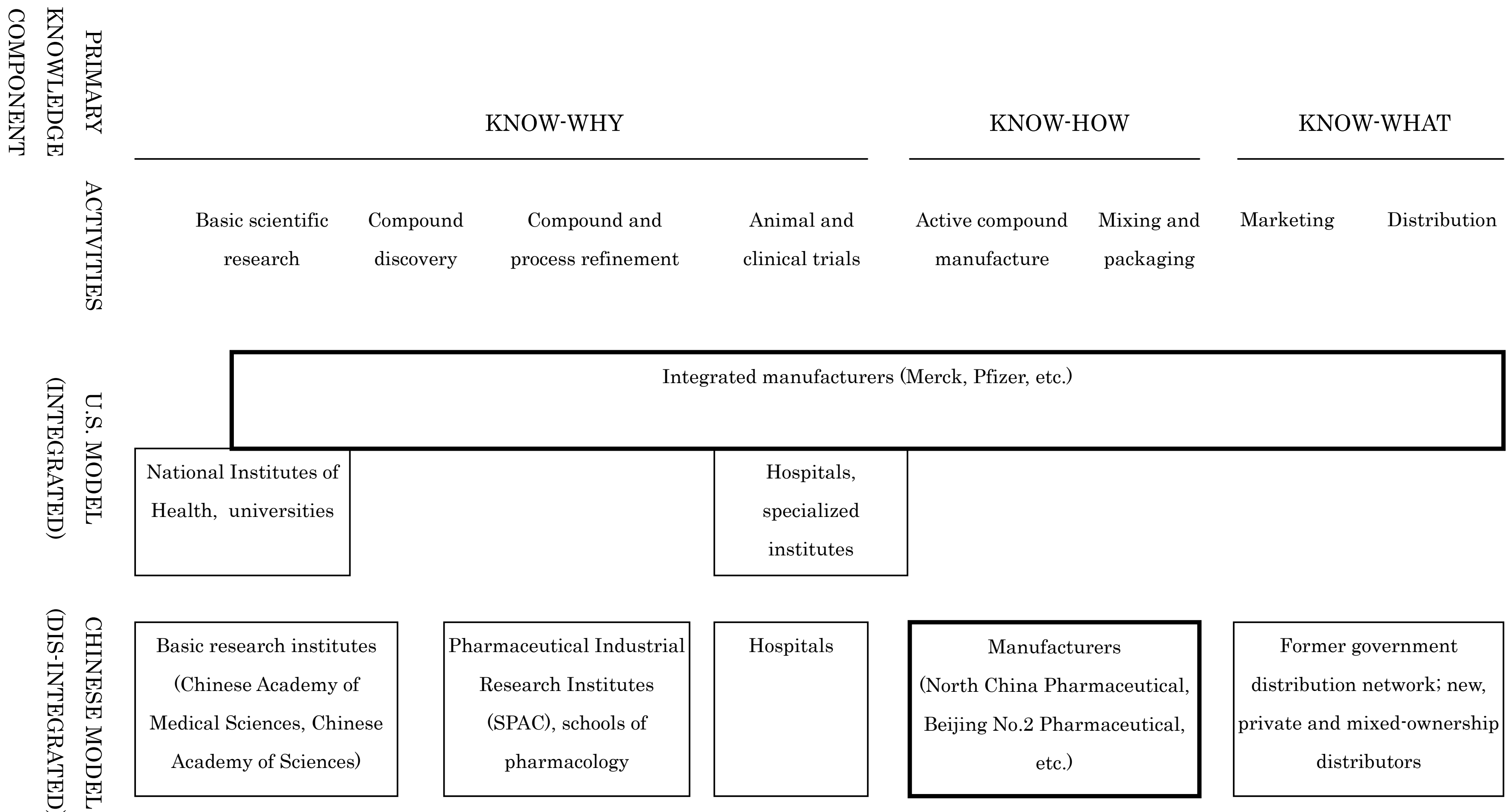


FIGURE 3
Interorganizational collaboration in pharmaceutical-related scientific articles

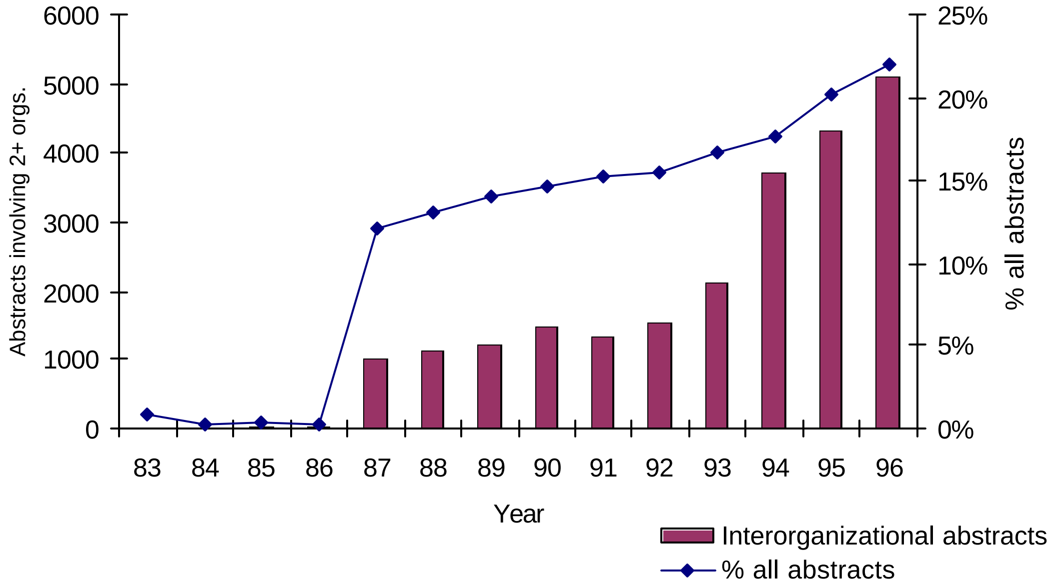


FIGURE 4
Types of organizations involved in pharmaceutical-related R&D

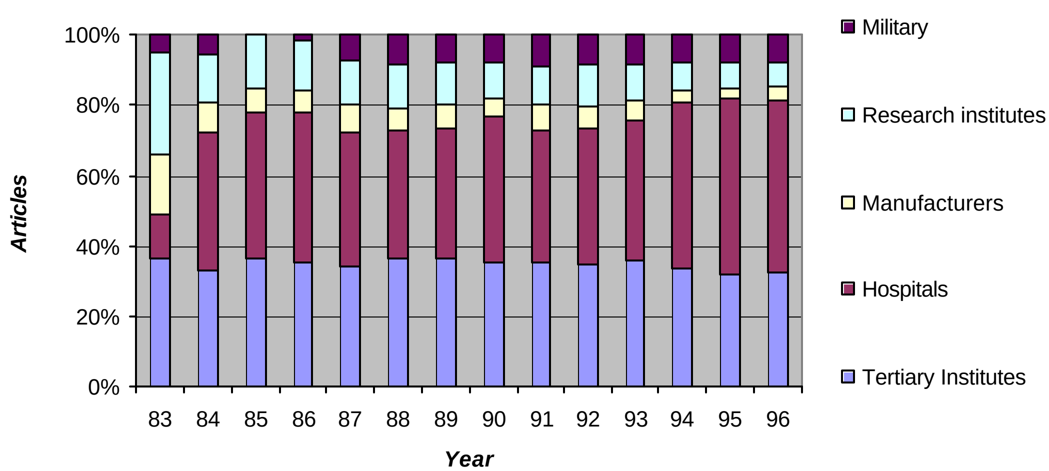


FIGURE 5
Joint authorship in pharmaceutical-related scientific publications

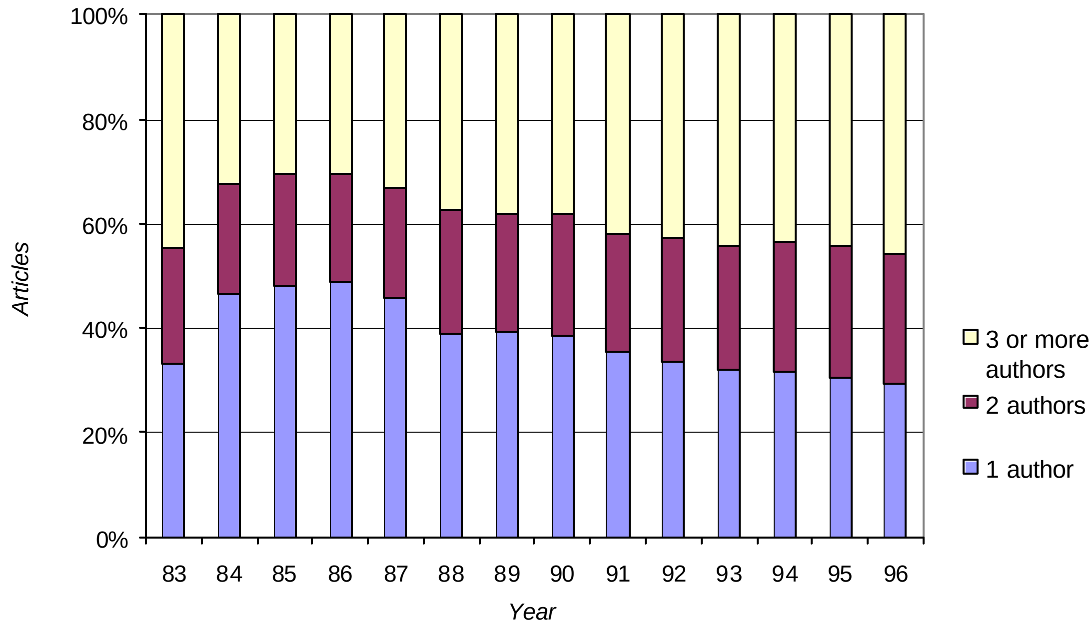
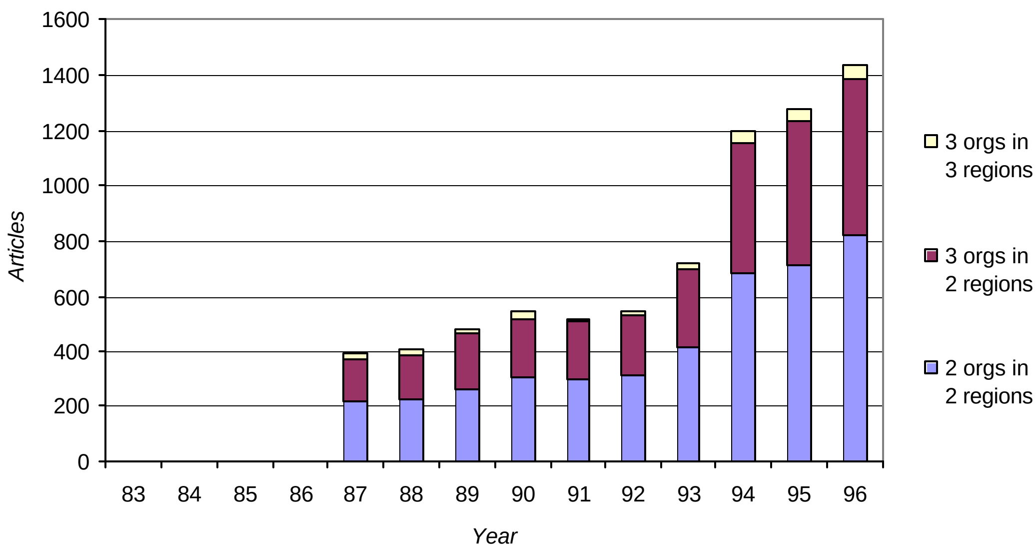


FIGURE 6
Inter-regional trends in pharmaceutical-related scientific publications



Using Research and Development to Grow State Economies

DAN BERGLUND and MARIANNE CLARKE

FOREWORD

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1. SUMMARY

The U.S. economy is undergoing a dramatic transformation as the nation moves to an economy driven by technology industries and the application of technology in traditional industries. To compete in this "new economy," states must have an economic base of firms that constantly innovate and maximize the use of technology in the workplace. Also critical is a strong research and development (R&D) base that can provide these technology-intensive companies with access to state-of-the art research, researchers, and research facilities.

ELEMENTS OF A TECHNOLOGY-BASED ECONOMY

A technology-based economy requires:

- a strong intellectual infrastructure, such as universities and public or private research laboratories that generate new knowledge and discoveries;
- efficient mechanisms through which knowledge is transferred from one person to another or from one company to another;
- excellent physical infrastructure, including high-quality telecommunications systems and affordable, high-speed Internet connections;
- a highly skilled technical workforce; and
- good sources of capital.

Each element has a direct impact on a state's R&D base and, therefore, on its ability to support a technology based economy. Many states are building their R&D base through initiatives that address these elements.

Intellectual Infrastructure. The university system is an important component of a state's intellectual infrastructure. A recent report by the Milken Institute found that of the top thirty high-technology metropolitan areas, twenty-nine were home to, or within close proximity of, a major research university.[1] States can improve the intellectual infrastructure by strengthening the R&D capacity of their higher education system, investing in higher education in areas of industrial relevance, and encouraging greater university-industry interaction.

Spillovers of Knowledge. Much of the success of Silicon Valley can be attributed to its accomplishments in transferring knowledge and technology from universities to the private sector and among companies. States can encourage spillovers of knowledge by identifying and removing barriers to the commercialization of university developed technology, encouraging access to federal laboratories, and providing seed funding to industry associations and technology councils that promote communication among companies.

Physical Infrastructure. The competitiveness of a state's economy increasingly depends on its enabling infrastructure. In the past, this meant roads, bridges, and rail and telephone systems. Today, it also includes proximity to airports, fiber optic networks, and high-speed Internet access. States can examine the quality of their physical infrastructure and take steps to improve it through public and private action.

Technically Skilled Workforce. Perhaps the most significant issue facing technology-intensive companies today is access to an adequate number of highly skilled technical workers. More than 300,000 information technology jobs were unfilled in 1998, according to a report by the Information Technology Association of America.[2] The U.S. Bureau of Labor Statistics projects that an additional 2 million workers will be needed during the next ten years.[3] States can help ensure the availability of a technically skilled workforce by encouraging more students to enter science and engineering fields, developing internship programs for students in science and engineering, and providing training for workers in technology-based companies.

Capital. The availability of capital to support start-up and emerging companies—the type of companies on which the new economy depends—is essential if a region is to build its R&D base. Although the supply of venture capital in the United States has increased dramatically in recent years, venture capital investments are geographically concentrated. Consequently, venture capital is not available in all regions. In addition, as the size of venture funds have grown, fewer investments are being made at the preseed or seed stage. State options to address the need for venture capital include investing state funds in technology companies, using state funds to leverage private funds to invest in technology companies, helping companies access private and public funding sources, and offering R&D tax incentives.

2. IMPLICATIONS FOR A STATE'S RESEARCH AND DEVELOPMENT BASE

Technology industries are driving the new economy. States that position themselves to take advantage of this changing economic environment will realize its benefits; those that do not will see a widening income gap and declining revenue base. Growing state economies in this new century will require building a strong R&D base to support the burgeoning technology industries. To participate fully in the new economy, states should take several actions.

Develop a plan for building the R&D base. The first step is to develop a clear plan for building the R&D base. The plan should reflect the vision for the state's future, be based on a thorough understanding of the state's economy and R&D assets, and benefit all areas of the state.

Recognize that building the R&D base means a long-term, sustained, and significant investment. There is no quick route to acquire a thriving R&D base. Silicon Valley in California, Route 128 in Massachusetts, and Research Triangle Park in North Carolina are the results of decades of public and private investment. For example, North Carolina invested hundreds of millions of dollars during more than twenty five years to support its universities and the research park's development. Most policy options to build an R&D base require a long-term, sustained, and significant investment.

Hold initiatives accountable. State policymakers should determine in advance what policies and programs aim to accomplish and how results will be measured. Given the long-term nature of R&D investments, both interim and long-term performance measures should be developed and implemented.

3. THE CHANGING ECONOMIC ENVIRONMENT

In 2050 Americans will look back with an understanding that the U.S. economy was transformed in the last decade of the twentieth century. The nineteenth century's transition from an agrarian-based economy to a manufacturing-based economy is paralleled in today's transition from a manufacturing-based economy to a technology-based economy. Unquestionably, agriculture and manufacturing will continue to be important economic sectors, but the new economy will be driven by technology industries and their influence on traditional economic sectors. The changing economy has been dubbed the new economy, the digital economy, the knowledge-based economy, and the technology-based economy. All are accurate descriptions of an economy that is becoming less dependent on making and growing things and more dependent on promoting ideas and innovations. The new economy also is less reliant on natural resources and more dependent on human resources.

3.1 THE IMPORTANCE OF TECHNOLOGY AND TECHNOLOGY FIRMS

Technical innovations have spawned new products and industries, including personal computers and cellular phones and electronic commerce (e-commerce) and biopharmaceuticals. They can improve the quality of people's lives by providing medical advances, a cleaner environment, enhanced communication, and more entertainment options. The technology-based economy holds great promise for simplifying lives by providing easy access to information and improving health care through telemedicine. Yet the challenges posed by this economy are as profound as its benefits. Income disparity among regions and people may widen considerably as some participate fully while others are left behind. The economic importance of high-technology firms in today's economy can hardly be overstated. Employees in high-technology industries make significantly more than those in other industries. In 1996 the average pay per employee in high-technology industries was 67 percent higher than the average pay per employee for all other industries, $44,041 compared with $26,363.4 Information technology, a component of high-technology, is credited with one-third of U.S. economic growth between 1995 and 1998, according to the U.S. Department of Commerce.[5]

Perhaps even more significant than the current economic impact of high-technology firms is the actual and projected growth of the industries. The Internet and e-commerce alone will fundamentally change every industry in the coming decades. E-commerce among businesses began roughly in 1995; by 2002 it is expected to account for about $300 billion worth of transactions[6]. As high-speed Internet access becomes commonplace, businesses and people will purchase products and services directly from the supply source, removing or reducing the role of various parts of the supply chain. For example, online travel sales are expected to grow twenty times during a four-year period[7]. Although people will be able to make travel arrangements at their own convenience, it will result in the closure of thousands of travel agencies across the nation. Similar scenarios can be forecast for the insurance, banking, and real estate industries, automobile dealerships, and video rental stores. Small businesses that survive in this environment will likely be focused in niche geographic or market areas.

3.2 INVESTMENT IN RESEARCH AND DEVELOPMENT

For more than forty years, states have been taking advantage of their R&D assets to improve their economic future. North Carolina's Research Triangle Park (RTP) was one of the earliest efforts. Created in 1959 through a public-private partnership involving business, academia, and state government, RTP seeks to build on and encourage greater cooperation among Duke University, North Carolina State University-Raleigh, and the University of North Carolina-Chapel Hill. Its efforts to attract companies to locate R&D facilities within the park have resulted in more than 100 R&D facilities. These facilities employ more than 37,000 people with combined annual salaries of more than $1.2 billion[8].

However, in today's global economy, state policymakers must be aware not only of the actions of other states, but also of other countries. Recognizing that a strong R&D base is critical in the technology-based economy, nations worldwide are increasing their investments in their R&D base. Although many European countries have invested heavily in programs designed to promote economic growth through the application of science and technology, countries in Asia and the Americas are also making significant investments. Approaches include funding R&D, offering tax and other incentives to attract and grow technology-based companies, and providing financial and technical assistance to entrepreneurs and new start-up technology companies. As in the United States, foreign governments are encouraging government-industry and university-industry partnerships, and subnational levels of government have begun to offer incentives and support for technology-based companies.

In recent years, Singapore, South Korea, and Taiwan have made tremendous strides in building a technology based economy. South Korea and Taiwan, both major suppliers of computer equipment to the United States, dramatically increased their patent activity in the late 1980s, and they continue to aggressively pursue technology commercialization. Singapore is making substantial investments to promote a climate for innovation. Through its National Innovation Framework, Singapore's National Science and Technology and Economic Development Boards have committed $2 billion during the next five years to support the development of industry-driven R&D. These funds will be used to build infrastructure, support university-industry collaboration, recruit and develop R&D-trained personnel, and commercialize technology[9]. Taiwan's Industrial Technology and Research Institute, a government-funded, nonprofit intermediary organization, seeks to bridge the gap between university research and industry needs by coordinating research, analyzing industrial trends, conducting market assessments, and gathering global competitive intelligence.[10]

While Singapore and Taiwan are positioning themselves to participate fully in the technology-based economy, other countries, including Ireland and Israel, have clearly established themselves as key competitors. Ireland, which has succeeded in attracting a large number of multinational information technology and electronics corporations, is now seeking to grow its base of technology companies, with an emphasis on software development. A key strategy is building a strong R&D base in its universities and businesses. Its National Research Support Funding Board administers grant programs that fund basic research and joint industry university projects. Ireland also has made a commitment to encourage Irish industry to invest in R&D. The Research Technology and Innovation Initiative, launched in late 1997, provides grants to Irish companies meeting certain criteria to cover between 35 percent and 50 percent of the costs incurred for a research project, depending on its size.[11]

Israel has built on its strong base of defense-related technologies and capitalized on its highly skilled, technical workforce. The country has one of the highest per-capita ratios of scientists and engineers in the world. Like Ireland, Israel has succeeded in attracting corporate investment by providing financial and tax incentives to build the country's industrial base. Israel also provides incentives for R&D investments.

Clearly, policymakers around the world are developing strategies to take advantage of the technology-based economy. Areas that thrive will boast a strong and vibrant research and development base. For state policymakers to develop that base, they must understand what sectors comprise the U.S. R&D base and what elements are needed for a technology-based economy.

4. COMPOSITION OF THE U.S. RESEARCH AND DEVELOPMENT BASE

Four sectors comprise the largest part of the U.S. R&D base: the private sector, colleges and universities, the federal government, and state government. State action can influence each sector's effect on the technology-based economy.

The private sector is by far the largest R&D performer in the United States, accounting for 70 percent of R&D spending in 1995. Most R&D performed by the private sector is focused on development; knowledge or understanding gained from research is directed to producing useful materials, devices, systems, or methods, including products and processes. Colleges and universities are the second largest R&D performer, accounting for about 12 percent of R&D spending. They focus primarily on basic research designed to gain greater knowledge or understanding, with limited attention to specific applications. The federal government, including federal laboratories, performs 9.4 percent of the nation's R&D, with some emphasis on development. Often overlooked, states spent more than $3 billion on R&D in fiscal 1995. Most of this spending was for basic research.[12]

5. ELEMENTS NEEDED FOR A TECHNOLOGY-BASED ECONOMY

Most states envy the economic triumphs of Silicon Valley, Route 128, and Research Triangle Park, and there is no simple formula to replicate the success of these technology-based meccas. However, research on technology clusters points to seven elements that are critical to building a technology-based economy[13]. These elements can be grouped into tangible elements—those that are definable and measurable—and intangible elements—those that can be defined only subjectively and are difficult to measure. There are five tangible elements.

Intellectual infrastructure. In a technology-based economy, a key component for success is a thriving source of new ideas with people who advance their field. This source could be any one of the four sectors already performing R&D or ideally some combination of the four.?

Spillovers of knowledge. A technology-based economy also requires a free flow of ideas or spillover of knowledge. This movement can occur formally, for example, through invention licensing, or informally, for example, through the migration of employees.

Physical infrastructure. Although a technology-based economy holds out the prospect that people can work wherever they like, an excellent physical infrastructure is still required. In addition to good highways and proximity to airports, physical infrastructure in today's economy also means high-quality telecommunications systems and affordable, high-speed Internet connections.

Technically skilled workforce. In an economy that is based more on ideas than on manual labor, knowledgeable people with technical skills are fundamental to success. Companies are more likely to locate in areas where a supply of technically skilled workers exists than in areas where training to upgrade workforce skills is needed.

Capital. For companies to grow, they must have capital. Regardless of the stage or source of capital, companies need financing to expand.

There are two intangible elements.

Entrepreneurial culture. The intangibility of entrepreneurial culture makes it difficult to define. However, in an entrepreneurial culture, people view starting a company as a routine rather than an unusual occurrence, entrepreneurs are celebrated, individuals know many others who have started their own company, and people view company failure as a possible outcome of doing business rather than a cause for social disgrace.

Quality of life. Quality of life is subjective and largely in the eye of the beholder, so it can translate into different things for different people. For example, some may view as important low taxes, varied cultural and recreational opportunities, a strong education system, and proximity to environmentally protected areas. In a technology-based economy, companies have more freedom to locate, and quality of life could play a more important role in their decision than it has in the past.

Each tangible element has a direct impact on the R&D base. An inadequate intellectual infrastructure strangles the technology-based economy of ideas and innovations, its lifeblood. Similarly, if spillovers of knowledge are not occurring, the R&D performers cannot build on others' research. A substandard physical infrastructure prevents the R&D performers from communicating with one another. Without an adequate supply of qualified workers, the research cannot be conducted. A lack of capital bars the R&D performers from paying for research and development. States can influence the tangible elements needed for a technology-based company. Difficulties in defining the intangible elements sometimes limit or preclude state action.

5.1 INTELLECTUAL INFRASTRUCTURE

For a state, the strength of its university system is probably the most critical element in the technology-based economy. Although the university R&D base can be measured in different ways, perhaps the most widely accepted is the classification of institutions of higher education developed by the Carnegie Foundation for the Advancement of Teaching[14]. The 1994 classification includes all colleges and universities in the United States that are degree-granting and accredited by an agency recognized by the U.S. Department of Education. The foundation classifies these institutions based on the number and type of degrees they award and the level of federal research support they receive.

The highest classifications are Research University I and Research University II.

- A Research University I awards fifty or more doctoral degrees each year and receives $40 million or more annually in federal support.
- A Research University II awards fifty or more doctoral degrees each year and receives between $15.5 million and $40 million annually in federal support.

For the 1994 classification, which is the most recent, 126 universities in forty-three states fit the criteria. Alaska, Maine, Montana, Nevada, New Hampshire, North Dakota, and South Dakota lacked institutions meeting the criteria.

A recent report by the Milken Institute identifying the top fifty high-technology metropolitan areas suggests the significance of universities in the technology-based economy. Of the top thirty high-technology metropolitan areas, twenty-nine are either home to, or within close proximity of, a Research University I or II.[15]

To improve the intellectual infrastructure, states can:

- strengthen the R&D capacity of the state's higher education system;
- invest in higher education in areas of industrial relevance; and
- encourage greater university-industry interaction.

5.1.1 STRENGTHEN THE R&D CAPACITY OF THE STATE'S HIGHER EDUCATION SYSTEM

Recognizing the importance of a strong university system to the state's economic future, Nebraska created the Nebraska Research Initiative (NRI) to strengthen the research capabilities of the University of Nebraska. NRI aims to enhance the state's basic and applied research capacity, develop the state's national and international competitiveness, diversify the state's economy and bring job opportunities to the state, improve Nebraska's workforce, and improve the state's competitiveness in attracting research funds. In 1988 the state planned to increase the university's base budget for research by $4 million per year for five years, so that by 1993, NRI's annual budget would be $20 million per year; however, the spending was capped at $12 million per year. NRI has used the additional funding to support research centers focused on biotechnology, engineering, materials, telecommunications, and water sciences. As a result, Nebraska has seen its rank in the amount of funding it receives from the National Science Foundation climb from forty-sixth in 1990 to thirty-seventh in 1997. The rank for most states remained static during this period.[16]

5.1.2 INVEST IN HIGHER EDUCATION IN AREAS OF INDUSTRIAL RELEVANCE

States can also bolster the intellectual infrastructure by targeting state funds to research areas of particular strength. Typically, the areas are selected based on university capabilities and the existing industrial base. Investing in research when there is no corresponding private-sector base is less likely to result in positive economic development impacts for the state. Georgia is targeting research through the Georgia Research Alliance (GRA), which it founded in 1990 as a partnership involving the state's research universities, industry, and state government[17]. GRA fosters economic development within Georgia by developing and leveraging the research capabilities of the state's research universities. It also develops and assists scientific and technology-based industry, commerce, and business.

Advanced communications, biotechnology, and environmental technologies are strategic areas for research. Centers formed around each area promote cross-disciplinary and cross-institutional research and facilitate the transfer of technology to applications relevant to industry. GRA is leveraging the research capabilities by constructing new facilities, installing state-of-the-art equipment, and recruiting eminent scholars.

Public and private funds support GRA programs. Through fiscal 1998, the state had invested $200 million in R&D programs at the universities, an amount matched by $50 million in private funds. This funding has helped attract more than $500 million in additional sponsored research. GRA also cites as an example of its success Lucent Technologies' decision to choose Atlanta for its new wireless laboratory. The decision resulted from the company's close working partnership with researchers at a GRA-funded center and GRA's commitment to establish an eminent scholar chair and develop a laboratory in wireless systems at Georgia Tech.

More recently, Michigan has announced a strategy to build its universities' capabilities in life sciences[18]. The state is planning to spend $1 billion of tobacco settlement funds during the next twenty years for life sciences research, development, and commercialization. The intent is to create a "life sciences corridor," making four research institutions—the University of Michigan, Michigan State University, Wayne State University, and the Van Andel Institute—national leaders in biotechnology applications.

The annual allotment will be divided among three program areas:

- forty percent will support a basic research fund that will be distributed to projects from the four institutions on a competitive basis;
- fifty percent will go to a collaborative R&D fund, with an emphasis on testing or developing emerging discoveries in partnership with biotechnology firms; and
- ten percent will go to a commercialization development fund to invest in start-up biotechnology companies.

5.1.3 ENCOURAGE GREATER UNIVERSITY-INDUSTRY INTERACTION

State matching grants for research partnerships encourage greater university-industry interaction and improve the intellectual infrastructure for the private sector. More than thirteen states have an ongoing program to fund university-industry partnerships. These programs tap the significant investments that states make in their higher education system and help bridge the gap between university and industry cultures.

Born out of the depths of Ohio's worst economic downturn since the Great Depression, the Edison Program is one of the nation's largest university-industry partnership programs[19]. The bulk of the program funding is invested in seven technology centers. These university-industry consortia were selected through a competitive process, and they are located throughout the state. They focus on Ohio's traditional and emerging strengths in advanced manufacturing, polymers, materials, welding and joining, and biotechnology.

The technology centers must provide at least a 1:1 match of state funds with industry membership fees, research contracts, federal grants, and donated equipment. Each center is unique in its organization and management, but all of the centers are independent, 501(c)(3) nonprofit organizations. A majority of each center's board of trustees must come from the private sector to ensure that industry is driving the center's agenda.

Some centers have in-house research staff who are supported by university professors, while others have a small administrative staff who coordinate and oversee research at member universities, federal laboratories, and companies. Each center provides technical services, research, and networking opportunities for its members. Membership fees are based on company size and range from $100 for a small business to more than $100,000 for a Fortune 100 company. At some of the centers, members can earmark a portion of their membership fees for specific services such as proprietary research.

5.2 SPILLOVERS OF KNOWLEDGE

States have experimented with ways to encourage spillovers of knowledge among companies and from universities to the private sector. Much of Silicon Valley's success is attributable not only to the world-class research conducted at Stanford University, but also to the university's policy of encouraging its faculty and students to commercialize their research. In addition to liberal-leave policies, Stanford sometimes provides investment capital for the start-up companies. Due, in part, to state and university policies, few universities are as proactive as Stanford was in the 1950s and 1960s. Some state statutes impede the transfer of technology from academic institutions to industry. Moreover, a university culture that rewards publications rather than interactions with industry is a significant barrier to faculty members who are interested in working with the private sector.

To encourage spillovers of knowledge, states can:

- identify and remove barriers to the commercialization of university-developed technology;
- encourage access to federal laboratories; and
- provide seed funding to industry associations and technology councils.

5.2.1 IDENTIFY AND REMOVE THE BARRIERS TO COMMERCIALIZATION OF UNIVERSITY-DEVELOPED TECHNOLOGY

As a result of the Bayh-Dole Act, which provided universities with the rights to intellectual property resulting from federally funded research projects, universities began setting up technology transfer offices in the 1980s. These offices review invention disclosures, identify technologies with commercial potential, manage the patent process, and license technologies. In 1997 universities responding to the annual survey of the Association of University Technology Managers (AUTM) reported almost $700 million in gross income from licenses.[20]

Despite the growth in licensing, increasing the flow of university technology into the commercial market remains a challenge. State policymakers should review barriers to commercialization, which may result from state law, university policy, or external factors, and develop plans to remove them. Common obstacles include restrictions on the use of university-owned equipment to benefit private companies, requirements on how faculty must spend their time, understaffed and underfunded technology transfer offices, and criteria for tenure that focus on publication rather than commercialization.

Removing the barriers to commercialization must be balanced with other public policy concerns. For example, commercialization can be encouraged by rewarding faculty who spend more time working with companies, but this focus could result in faculty spending less time in the classroom. Moreover, encouraging universities to license more technologies may not necessarily result in those technologies being commercialized in-state, though incentives could be crafted to encourage universities to work with companies located in the state.

Technology transfer “best practice” universities provide incentives for faculty members to support and participate in technology transfer activities. The promise of additional resources to continue their research is one of the best motivators for faculty to pursue commercialization. Several universities, including the University of California, Pennsylvania State University, the University of North Carolina, the University of Virginia, and the University of Wisconsin-Madison, changed their policy on the distribution of patent revenues to provide an additional incentive for faculty members to patent and license their inventions. In addition to changing the distribution of patent revenues, the University of California is reviewing its academic review process to find ways to recognize and reward faculty for receiving patents and licenses.[21]

Another approach to commercialize university research, and one that is receiving more attention, is to form start-up companies. Some universities provide business planning and marketing assistance to faculty wanting to start a company. Others play a more active role by helping identify strategic partners and, in some cases, providing seed capital. In 1997, 101 academic institutions responding to the AUTM survey reported forming 333 new companies[22]. It is becoming increasingly common for universities to take equity positions in companies in addition to receiving royalties and licensing fees.

Centennial Venture Partners is designed to leverage the R&D base of North Carolina State University. A limited liability company, it invests in companies that commercialize technologies developed at the university or that are affiliated with the university.[23]

In November 1998, Oklahoma took steps to reduce the barriers to commercializing university-developed technology. Voters statewide approved two initiatives to promote the commercialization of university research and support university innovation. Under Oklahoma law, public property could only be used for public purposes. One ballot initiative authorized the use of public property for certain projects that involve the research and development of a technology. A state college or university can now let a business use college or university property to work on technology projects, especially those linked to the institution. As a result of the second ballot initiative, state colleges and universities, as well as their employees, may own technology and equity in private businesses. The companies have to make a product or invent a process or other idea with help from the institutions or their employees. No appropriated tax dollars may be used to invest in the business venture.[24]

5.2.2 ENCOURAGE ACCESS TO FEDERAL LABORATORIES

Federal laboratories are a critical part of the R&D base, employing one-sixth of the nation's scientists and engineers. The more than 700 facilities located across the nation undertake cutting-edge research in numerous fields. In addition to having a significant economic impact on the communities in which they are located and providing the area labor pool with highly skilled workers, federal laboratories can assist companies in resolving technical problems.

The Wright Technology Network (WTN) was created in 1989 by Ohio and the U.S. Air Force to serve as a bridge between the private sector and Air Force laboratories. WTN facilitates technology transfer by linking federal laboratories, academia, and industry. It specializes in providing access to federal laboratory technology to solve business technical problems. WTN identifies needed expertise, locates sources of improved technology, and makes the link. It also brings potential products to a company's attention and minimizes the red tape involved in dealing with federal laboratories. The depth of research available through federal laboratories is evident in the list of fields in which WTN works, including medicine, automotives, general aviation, environment, construction, education, and law enforcement.[25]

5.2.3 PROVIDE SEED FUNDING TO INDUSTRY ASSOCIATIONS AND TECHNOLOGY COUNCILS

States can encourage spillovers of knowledge among firms by providing start-up funding for industry associations and technology councils. States such as Maryland, Virginia, and Washington have provided start-up funding for industry associations or regional technology councils that provide formal and informal means of networking. These groups offer opportunities for companies to develop business alliances and learn from others' experiences in raising capital, recruiting and retaining employees, and developing new markets. They can also become a potent political force, serving as a voice for the state's technology community and lobbying for actions beneficial to the technology community.

5.3 PHYSICAL INFRASTRUCTURE

With advanced telecommunications, companies and people have more flexibility in deciding where to locate. This prospect brings hope to geographically isolated regions that have lagged economically. However, for this potential to be realized, the physical infrastructure, in particular high-speed Internet access, must be in place. States can examine the quality of their physical infrastructure and take steps to improve it through public and private action.

During the past fifteen years, Iowa has invested more than $300 million to create the Iowa Communications Network (ICN), a statewide, state-administered, fiber-optic network[26]. ICN provides full-motion interactive video services, high-speed Internet access, and competitive long-distance telephone rates to the state's educational institutions, hospitals, medical facilities, and government agencies. Today, ICN includes more than 3,000 miles of fiber-optic cable reaching every county in the state. Every citizen resides within fifteen miles of a video site.

The impetus for creating the network was to ensure that all urban and rural regions of the state had equal access to educational resources. This was to be accomplished by providing the highest quality and technologically advanced telecommunications services. Today, ICN is used to provide distance learning, enhance educational opportunities for Iowa students, and deliver telemedicine services to rural residents. State agencies use ICN to conduct public hearings and train workers. The Venture Network of Iowa uses ICN to link entrepreneurs with potential investors.

At least three states—Iowa, Texas, and Virginia—have considered providing excess bandwidth to the private sector. States are able to buy large amounts of service from Internet service providers (ISPs), so they can secure volume discounts and pass them on to state agencies and universities. The three states have considered making those discounts available to the private sector to offer lower cost Internet access, but ISPs have raised objections to the states competing against the private sector.

Communities in Indiana, Iowa, Kentucky, Oregon, and Washington have taken action to develop municipally owned communications systems that offer high-speed Internet access and phone and cable television service. The communities, primarily in rural areas, believe the improved telecommunications system will have a positive economic development impact in retaining and attracting companies while improving the quality of life for their residents. The telephone companies in some of these states assert that such action results in unfair competition with the private sector. The communities counter that they are concerned about the lack of investment the companies are making in rural areas.[27]

5.4 TECHNICALLY SKILLED WORKFORCE

One of the most significant problems the private sector faces today is access to an adequate number of technically killed workers. Recent studies and company anecdotes clearly suggest a significant shortage of workers in key economic sectors, particularly information technology.

More than 300,000 information technology jobs were unfilled in 1998, according to a report by the Information Technology Association of America[28]. The information technology industry is particularly concerned because of the projected growth of the industry and increased demand for jobs. The U.S. Bureau of Labor Statistics projects that an additional 2 million workers will be needed during the next ten years[29]. In addition, the American Electronics Association reports that the number of high-technology degrees awarded by colleges and universities declined 5 percent between 1990 and 1996.

Compounding the difficulty for states in ensuring a technically skilled workforce is the global economy and improved telecommunications system. With worldwide Internet access, work can be farmed out to other countries with qualified workers. For example, automotive companies in Detroit hope to reduce product cycles for new cars to twenty-four months. One way to accomplish this is employing teams of engineers to work on the design in the United States and India. Engineers in Detroit can assign a problem to their team in India. With the time zone difference, the engineers in the Far East can work on the problem and get an answer back to their counterparts in Detroit by the next business day.[30]

A shortage of workers is a new dilemma for most state policymakers, who typically have had to focus on creating jobs rather than filling jobs. Although states have a track record in leveraging their R&D base, they are newcomers to workforce development for that base. However, some states are taking action to address the need for technology workers.

To help ensure a technically skilled workforce, states can:

- encourage more students to enter science and engineering fields;
- develop internship programs for students in science and engineering; and
- provide training for workers in technology-based companies.

5.4.1 ENCOURAGE MORE STUDENTS TO ENTER SCIENCE AND ENGINEERING FIELDS

More than fifteen Governors spoke about creating or expanding scholarship programs for college students in their 1999 state-of-the-state addresses[31]. Some of the scholarship programs are specifically directed to ensuring an adequate labor force for the state's R&D base.

Arkansas has a program to encourage more technically trained graduates of its colleges and universities and colleges to remain in the state. The state will forgive up to $2,500 of student loan debt annually for a maximum of four years and $10,000. The graduate must be employed full time in a high-demand technical position in Arkansas to receive the credit. For the current academic year, the fields of advanced manufacturing, computer and information technology, and biomedical and biotechnology are included in the program.[32]

Pennsylvania is using a two-pronged approach. When fully implemented, the state's incentives will provide assistance to approximately 23,000 Pennsylvania students and workers annually at a cost of $49.6 million per year. A SciTech Scholars program provides scholarships of up to $3,000 per year for a maximum of three years to full-time students earning a bachelor's degree in select science and technology fields. Scholarships are available for the second, third, and fourth years of a student's academic program. To qualify for a SciTech scholarship, students must maintain a 3.0 grade point average, complete an internship with a technology-intensive Pennsylvania company, and work in Pennsylvania for one year for each year of scholarship assistance. If the requirements are not met, the scholarship converts to a loan.

A second initiative, tagged a "GI Bill for the New Economy," provides up to $1,000 a year in scholarships for full-time students and current workers pursuing an associate's degree in select science and technology fields at community colleges or two-year private technical institutes. Workers attending school part time are eligible for a scholarship of up to 20 percent of their tuition and fees. Participants must maintain a 3.0 grade point average and complete their associate's degree, or the scholarship converts to a loan.[33]

5.4.2 DEVELOP INTERNSHIP PROGRAMS FOR STUDENTS IN SCIENCE AND ENGINEERING

Increasing the supply of potential workers is one step to address the need for a technically skilled workforce. In Virginia the Governor's Commission on Information Technology points out that even if all the workers could be produced immediately, the worker shortage would not end because employers want experienced workers. "Herein lies the dilemma: the only way to produce a sufficient number of experienced workers is to first hire less experienced workers and have them gain the experience they need on the job. Instead, we heard a whole host of reasons why companies cannot or will not hire newly trained candidates, and the gaps grow larger each day."[34]

To respond to that dilemma, Governor James S. Gilmore III has challenged Virginia's technology companies to hire 5,000 advanced high school and college students through a proposed Virginia Technology Internship Program. The three-year program would include tax incentives to students and businesses in the first two years and to students in the final year.[35]

5.4.3 PROVIDE TRAINING FOR WORKERS IN TECHNOLOGY-BASED COMPANIES

States can also target worker training funds to technology-based companies. Maryland's Partnership for Workforce Quality provides matching funds for companies to upgrade their employees' skills. The program provides grants to reimburse companies for up to half the cost of training for new technologies and processes. Grants are provided to companies with fewer than 500 employees.[36]

6. CAPITAL

Capital to support start-up and emerging companies—the types of companies on which the new economy depends—is critical if a region is to build its R&D base. The good news is that the supply of private venture capital in the United States has increased greatly in the 1990s. In 1998 more than $14 billion of venture capital was invested in more than 2,800 companies. The bad news is that venture capital investments are geographically concentrated, with Silicon Valley alone receiving one-third of the investments, so venture capital is not always available in all regions.[37]

In addition, most areas face a shortage of seed capital—typically less than $1 million to $2 million of investments provided in increments of $250,000 to $500,000—and preseed capital—typically investments of $50,000 to $250,000. Traditional institutional venture capitalists are not providing preseed or seed capital. At one time the amount of traditional venture capital invested at the seed stage was tracked; however, several years ago, when the share became less than 2 percent, this category was no longer reported separately.

To encourage greater access to capital sources to invest in the private-sector R&D base, states can:

- use state funds to invest in technology companies;
- use state funds to leverage private funds to invest in technology companies;
- help companies access private and public financing sources; and
- offer R&D tax incentives.

6.1 USE STATE FUNDS TO INVEST IN TECHNOLOGY COMPANIES

One of the oldest programs that provides financing to technology companies is the Massachusetts Technology Development Corporation (MTDC)[38]. Created in 1978, MTDC, a state-sponsored venture capital company, has a longer track record than many state initiatives. MTDC is a source of early-stage risk capital. Since 1988, it has been entirely self-supporting. The corporation was created to address the capital gap for start-up companies and encourage the growth of early-stage technology firms. Throughout its existence, MTDC has pursued four basic objectives:

- help create jobs in technology-based industries in Massachusetts;
- attract and leverage private investment in Massachusetts companies;
- foster the application of technological innovations where Massachusetts companies are, or can be, leaders; and
- nurture entrepreneurship among Massachusetts citizens.

Initial funding for MTDC came from a $2-million grant awarded by the U.S. Department of Commerce's Economic Development Administration (EDA) in 1979. These funds were used to establish a revolving loan fund for Massachusetts companies with operations that involved a significant amount of technology and were located in an EDA-eligible area. In 1981 EDA awarded an additional $1 million for a second revolving loan fund to help develop small, innovative, high-technology companies in Massachusetts. The commonwealth provided $1 million in matching funds. Each year from 1982 to 1988, Massachusetts appropriated additional funds totaling $4.2 million.

MTDC seeks to make all of its investments on a co-venture basis with private-sector investors, including venture capital firms, banks, limited partnerships, and individual and corporate investors. Investments can range up to $500,000, but typically MTDC provides between $100,000 and $300,000 of an investment of $1 million to $1.5 million. The balance is provided by private co-investors. Investments are made as debt, equity, or a combination of debt and equity. MTDC's staffs negotiate the exact terms of the investment with each company.

MTDC focuses on companies seeking small amounts of venture capital in the range of $1 million to $2 million. The size of the total fund of private venture capital firms typically ranges between $200 million and $800 million, so they are not usually interested in making such small investments. MTDC also differs from private venture capital firms because it is more willing to invest in an entrepreneur who has yet to establish a track record.

From 1980 until June 1999, MTDC invested $35 million in eighty-seven companies. Of its original investments, MTDC has exited or begun to exit sixty companies. As of December 1997, the companies in which MTDC had invested reported that they employed more than 8,600 people with an annual average salary of $49,900, generated an annual payroll of more than $431 million, and provided state tax revenue of more than $19.6 million. In addition, MTDC's investments have helped leverage additional private capital. As of June 1998, MTDC's investment of $35 million had leveraged $173.7

million. The firms in which MTDC initially invested raised an additional $265.8 million in subsequent rounds of investment in which MTDC did not participate.

6.2 USE STATE FUNDS TO LEVERAGE PRIVATE FUNDS TO INVEST IN TECHNOLOGY COMPANIES

In 1990 the Maryland general assembly passed legislation authorizing the Venture Capital Trust to increase the availability of seed and early-stage venture capital in the state[39]. The program created a state-sponsored but privately managed venture trust that was designed to become a "fund of funds," investing state and city pension funds in diverse venture capital partnerships managed by different venture capital firms.

The trust spent two and one-half years obtaining $19.1 million in commitments from state and city pension systems. In addition to the $2-million initial commitment from the state, the Maryland State Retirement and Pension System invested $15 million. The Employees' Retirement System of the City of Baltimore invested $840,000, and the Fire and Police Employees' Retirement System of the City of Baltimore invested $1.26 million.

The accomplishments of the Maryland Venture Capital Trust can be measured in terms of the economic benefits to the state and financial performance of the funds. By December 1996, the trust had invested $15.8 million in eight partnerships. Public stock offerings and private sales of several companies in four of the partnership portfolios have already returned $3.7 million to the trust, reflecting the trust's partnership interests in those companies. However, the trust's annual report notes that the eight venture capital partnerships have an operating life of eight to ten years, a period during which their investment cycles should be complete and their rate of returns realized. The overall financial performance of the trust can only be measured during a similar number of years.

The trust has succeeded in leveraging its resources. Total investment in the eight venture capital partnerships is $327 million. By the end of 1996, the eight partnerships reported that they had invested approximately $50 million in twenty-nine Maryland companies, more than two and one-half times the trust's initial investment of $19.1 million. Six of the firms have met or exceeded the minimum goal for investing in Maryland companies; the two that have not met their goal are still in the early stages of finding investments. The twenty nine Maryland companies in which investments have already been made have combined annual sales of more than $600 million and employ more than 2,400 people.

6.3 HELP COMPANIES ACCESS PRIVATE AND PUBLIC FINANCING SOURCES

States can use other means to provide access to financing sources in addition to providing funding for direct and indirect investment in the private-sector R&D base.

ACE-Net. The Access to Capital Electronic Network (ACE-Net) is a national securities offering listing service that enables venture capitalists and accredited institutional and individual investors to find small, growing companies through a secure Internet database. The day-to-day operations are managed by regional network operators that are nonprofit, university- or state-based entrepreneurial development centers.[40]

Venture Capital Conferences. Typically sponsored by states, chambers of commerce, or nonprofit organizations, venture capital conferences or fairs provide entrepreneurs with an opportunity to present their business plans to accredited investors. Investors and entrepreneurs then negotiate investment conditions on a case-by-case basis. The conferences vary from focusing on a community, a state, or multiple states, depending on the level of potential deals available.

Federal R&D Programs. Federal programs such as the Small Business Innovation Research (SBIR) program and the Advanced Technology Program (ATP) are other sources of capital for technology companies. The two programs provide more than $1.2 billion in research funding each year. Forty-eight states have some structured SBIR promotion or assistance effort under way. In fiscal 1998, states spent more than $8 million to promote participation in the federal SBIR program. They held more than 100 workshops, conferences, and seminars reaching thousands of businesses. State service providers estimate that 8,400 individuals and companies received information or assistance in 1998.[41]

6.4 OFFER R&D TAX INCENTIVES

Tax incentives are another way to encourage development of the private-sector R&D base. The most recent comprehensive report on state R&D tax incentives found that thirty-five states have some type of tax incentive. Any of these states offer an income tax credit modeled after the federal research and experimentation tax credit. Other types of incentives include sales and use tax credits and property tax credits. Only sixteen of the thirty-five states can provide information on the impact of their tax incentives in terms of the number of companies using the incentives and the resultant tax expenditures.[42] This lack of tracking to assess the impact of R&D tax incentives should concern state policymakers. Moreover, no studies have been done to evaluate the impact of state R&D tax incentives on the private-sector R&D base.

7. OUTLOOK FOR STATE POLICYMAKERS

Technology industries and the application of technology in traditional industries are changing the fundamental economic structure of the nation. Areas that are prepared to participate in the new technology-based economy will benefit; those that are not will see a widening income gap and declining revenue base. Five elements are critical in this economy: intellectual infrastructure, spillovers of knowledge, physical infrastructure, a technically skilled workforce, and capital.

Some states are taking steps to ensure the availability of these key elements. States that have not yet begun to respond to the changing economic environment should act now to do so. States can use research and development to grow their economies. A strong R&D base attracts and supports technology-intensive companies by providing access to state-of-the-art research, researchers, and research facilities. Using research and development to grow state economies will require states to develop a plan for building the R&D base; recognize that building the R&D base means a long-term, sustained, and significant investment; and hold initiatives accountable.

7.1 DEVELOP A PLAN FOR BUILDING THE R&D BASE

The first step is to develop a clear plan for building the R&D base. The plan should reflect the vision for the state's future, be based on a thorough understanding of the state's economy and R&D assets, and benefit all areas of the state. Developing this plan should be a joint public-private effort designed to obtain a wide range of viewpoints.

7.2 RECOGNIZE THAT BUILDING THE R&D BASE MEANS A LONG-TERM, SUSTAINED, AND SIGNIFICANT INVESTMENT

Silicon Valley, Route 128, and Research Triangle Park are the results of decades of investments, so policymakers should recognize up front that they are charting a course for future generations. Although there will be successes in the short term, there will also be failures. Research and development do not bear fruit overnight, and R&D investment is inherently risky.

Most of the policy options to build the R&D base will require a long-term, sustained, and significant investment by the state. The size of the investment signals to private businesses and universities the state's level of commitment. Some R&D initiatives have failed, in part, because the state, the private sector, or the universities were unwilling to make the necessary commitment.

7.3 HOLD INITIATIVES ACCOUNTABLE

State policymakers should determine in advance what programs and policies aim to accomplish and how results will be measured. The payoff of research and development is rarely immediate, so ongoing accountability is key.

Given the long-term nature of these investments, both interim and long-term performance measures should be developed and implemented.

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Start-Up Companies and University Technology

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Thank you very much for the opportunity to be here. The topic here is "Start-Up Companies and University High Technology Entrepreneurship." I will present a montage of different kinds of research that I've done If you care for more information, I'd be happy to send you the actual article.

First of all, let us spend just a minute talking about some of the changes in university technology plans for patenting and licensing, then talk about four different areas of information. Why is it that in the United States some universities have generated more startup companies to exploit their technology than others? Then secondly, let us look at which types of inventions came to be exploited by startup companies. Third, I shall look at some issues about the financial processes of university startups, and lastly what kinds of technical projects are startup companies particularly good at commercializing, and where are they not so good?

Our data source is a study of all MIT patents from a period in 1980 to 1996. We looked at all of the efforts to commercialize MIT patents, that is, all efforts by private sector licensed teams to make a product from MIT technology. We looked at those over the period from 1991 to 1998, using data from the technology licensing offices of 105 US universities that belong to the national association of technology licensing managers. We also made a survey of venture capital firms and finally a survey of 134 companies that set out to commercialize MIT patents. So I'd like to tell you that's where information is tending to come from.

As you know from other presentations of people here, there has been a large growth in University patenting over the past 20 years. David Mowery said there was five fold increase in university patents, many more patents from universities per dollar of research. There is also an increase in the commercial orientation of the technology, more royalty income to the universities. There is a much larger percentage of the work in the biological sciences than in the past. The new piece of information is that a much larger fraction of the technology is to people who want to start new companies. Since 1980 we have seen 3000 companies formed, just to exploit intellectual property from the universities.

Some of the startups became very successful. Even if you took just the market value of Serologic alone, which was created to exploit a single patent, its market capitalization is much larger than all royalties to all universities in that period. Now I shall discuss some specific trends.

The next figure shows the number of companies that did not exist prior to MIT granting a license on its patents.

One trend actually runs across all universities. The Figure shows the number of companies formed to exploit intellectual property, something assigned to the university across all U.S. universities that report data. And if you look at the data collection between 1980 and 1993 this was basically one third to one quarter the magnitude that was in the most recent year that the data was available. So we've actually had a very big increase in the recent years.

What it might account for this increased startup activity and there have been four kinds of arguments that people have made to explain why this should be the case. The first is, this is just a function of the growth of the biotechnology industry. Before the first year of all this data, in fact there wasn't a biotechnology industry. Biotechnology has the characteristic of strong dependence on patent protection and strong roots in university research, so it has been an unusually good vehicle for the stimulation of commercialization of university research.

The second is the influence of the Bayh-Dole Patent Act, which gives the university copyrights to government funded research and allowing them to assign those property rights to others. It allows people to start companies and try to protect their startup.

The third is the change in patent law making patents for a variety of reasons more valuable. Now the thing about startups is that before they get going the only thing they've got of any value is the intellectual property. They have no marketing; they have no manufacturing; they have no distribution, etcetera. So when a patent is a strongly made patent, there is created a strong incentive for creating what we call a startup company.

The last is a whole change in financing processes which is a fourth explanation, things like the SBIR program, which supports early stage commercial research in high tech areas. Then there is a series of things that relate to the creation of venture capital, funds that got universities very involved with interactions with the venture capital community.

Now what's kind of interesting although if you look at all the data, this is not the same across all universities? There's actually a significant variation as to which universities are creating startups and which aren't. Let's look at 1998, a book describing inventions disclosures reporting the ratio of startup firms for that university to the number of indications that something was invented in the university, you see that Harvard's ratio was a big fat donut [i.e. zero], whereas at MIT it was 5%.

When you go around Cambridge, that's kind of what people anecdotally chat about as a pattern they would expect. But why should that pattern be there? So one of the things that I did with a doctoral student is try to figure out why the startup rates vary so much from one university to another. We looked across, from '81 to '98 across, 105 U.S. universities. Now first let me tell you what didn't matter. We looked at the amount of venture capital in these different areas, in direct contrast to the private funding, and no matter how you manipulate the data it doesn't matter. We don't see evidence of a funding gap. Universities making their own venture capital investments, having tools within the university, make no difference. Having incubators made no difference. What did matter?

First of all, university equity in the startup mattered. Actually, when universities are willing to make an equity investment in up-front costs of the venture, the startup rate increased by 69%. So let me refer to the prior presentation about the perverse nature of incentives with royalties. The way that the royalty division is made, as Lew Branscomb pointed out, is that some portion of royalty income goes to the inventor, some goes to the inventor's department, and some goes to the university. If you want people to like established companies, you jack up the royalty rate share that the inventors get; they then have huge incentives to license. As soon as you do that, you lower their incentives to start the company themselves, and it's, they're going to earn the money anyway. They're going to get the royalties from their own inventions coming back to them. And what we find is, the more you increase the inventor's share of royalties, the less the incentive to start companies and you lower the startup rate. So if you're driving people in that direction, you're going to license the General Electrics, the Mercks of the world, and fewer will want to be entrepreneurs.

The third thing is university ambiance. This is controlling how much they like to invent, to patent. The higher the tendency to create intellectual property, the more prestigious the university. So there's something either about prestige, that is, people just believe that MIT guys have something that the guys from West Virginia might not have, or in fact that there is a true production of greater talent from the more prestigious and productive places.

The last thing is the more a project is industry financed, the greater the startup rate. That is, the lower the portion that's coming from universities (whether or not that may be coming from the government), the weaker the relationship. Now that led to kind of why some universities have more startups than others.

The next question is why some technical ideas out of the pool of intellectual property at one university, for example MIT, lead to startups but not others. We think that we've looked at the nature of the technological opportunity, the nature of the technology regime, or the industry in which that knowledge would be used, and the nature of the people.

University inventions are more likely when things are technically more important. That is, the greater the technological importance of an invention, the more likely is a university to create new technology. The more radical the scientific content of the invention, the greater the likelihood that it will be commercialized in a startup. The broader the scope of the patent, the more likely you are to see startups. The last point is, again, the argument that, in fact, if the intellectual property is the only thing that startups have, being able to protect that matters a lot.

What about the nature of the industries in which that intellectual property tends to be used? Well, first of all, startups tended to be more likely when the technical field was young, so that the newer patent classes of intellectual property, the more likely the university is to exploit it by creating companies. The second thing is, the more that markets tend to segment and create niches, the greater the likelihood there will be startups forming there. And the more that patents are effective in aligning business, that is, biotechnology, say, versus software, the more likely people were to start companies. The less important complementary assets were, in marketing and distribution, the more likely you are to see startups.

In terms of the people, we discovered four kinds of patterns. The first thing is that, in a particular piece of intellectual property, in a same invention, you can see patterns where people will discover opportunities that fit their prior background. Single MIT inventions could yield things in power plant filters, drug developing, etc., simply because people look at that technology to exploit it in different areas. Secondly, there tends to be an experience effect in the startup process. For every prior patent that an inventor had that led to a startup, there's an 8% increase in the probability that the subsequent inventions will lead to startups. There tends to be some sort of experience effect here. The third is that there tends to be status effect, that is, the higher the rank of the person in the university, the greater the likelihood of startup off of that technology. Now this could be the affect of having moved your way up the academic hierarchy, and being done with that, now can play around with other things. But we do know that there is linear increase in patenting with years after being granted tenure.

The last thing is that when patents tend to be weak in protecting intellectual property tends to be when inventors are the people who found the company. When patents are strong, the people who start the company tend to be people who go shopping at the technology license office, and this is consistent with a lot of economic theory about markets for knowledge, that when you have disclosure problems and markets for knowledge break down, the only way to do this is to internalize the transaction.

In terms of financing of universities startups, the first thing is that we see that there are very strong social relationship effects in startups. That is that people are much more likely to get funding for university startups if they have direct ties, that is, direct social or business ties, to investors or indirect ties -- the idea of referral or a third party connection. In fact, one of the things that we found, in looking at 134 MIT startups, is that the relationship with somebody who provides a referral, that is, I know somebody who can refer me to a venture capitalist, before starting a company, will increase the probability of getting venture capital by 20 times. Each $2 million of venture capital doubles the probability of an initial public offering (IPO) later. I know people who can refer me to venture capital, get me money, money gets me to an IPO, and that 25% of MIT startups eventually will go public. And there's a reverse pattern of, that failure rates are decreased in response.

The last piece of this process was to say, to what form of organization should this property be licensed? What about efforts to commercialize this technology and get it to products or services on the market? What we're doing here is comparing newly created companies, that is, companies created just to exploit this intellectual property against those that were already in existence. We see three patterns, three initial conditions, in which the startups are better at the commercialization process.

The first is that for industries with lots of firms, the startups are better. Industries with few firms are not; they are not for several reasons. There are several theoretical explanations for why this should be the case. This is probably not the place to go into them, but it's the fact that that's the case. The second is that when, industries tend to be manufacturing intense, that is a higher percentage of value added comes from manufacturing, startups are worse at commercializing those university inventions. The last thing is that when markets are large in the industry, startups are worse at commercializing, then when the markets are small.

In summary, there has been a very large increases in university startup activities in about the last 20 years, particularly in the biomedical field, and there's really no indication that trend has stopped at all. The second is that for startups, given that there' s a trend for everybody, there is also a variation within universities. In part that variation is just because of the policies that the university adopts, the relative prestige or ranking of the university, and the source of funding that the university has. Then at another level, now within a given university, within a given form of intellectual property, the nature of the technology, the nature of the technical regime in which that technology tends to be exploited, and the characteristics of the people influence the likelihood that there will be startups to exploit that invention. The financing prospects of inventions depend heavily on social relations within the process. And then lastly, the commercialization potential for startups varies as a function of the manufacturing intensity, and the number of firms inside that industry market.

Thank you.

China's High Technology Policy and Its National Technological Innovation System

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Abstract *From the modern history in China, there is a logic chain in the Chinese government to make a decision from scientific and technological policy to its high technology policy. Especially its high technology policy, as an important part of the public policy, has been made by the Chinese government from the foundation to mechanism of decision-making depending on the complicated political and economic circumstances of both home and abroad. And the result of such institutional arrangement was produced by the combination of the history and the present. As a core content of high technology policy, national technological innovation strategy play an important role to create a national technological innovation system which is a result of interaction and coordination between high technology policy and its development strategy. All of these show an important part of public policy in China.*

In this paper, along the history of policy-making of high technology in China, the author criticizes objectively the high technology policy from the mechanism of public policy, and researches the technological innovation strategy and the national technological innovation system seriously. The focus research is on how the inventions from public research organizations transfer to technological innovation in the national technological innovation system. Between the technology invention as a public good and the technology innovation as some commercial value, the Chinese government how to play its suitable role by its high technology policy. Meanwhile, the author also discussed the pooling and transferring between institutional resource and technological resource in the high technology field and the combination of the arrangement between micro-institution and macro-institution in its high technological innovation system. Based on the theory of the public policy, the author evaluated the national technological innovation system in China.

At the present, as the process of speeding globalization, the national competitiveness of any country in the world has been strategically depended on both of its research on high technology and its high technology industry. Therefore, the government of any country has to make an institutional arrangement as a government behavior to meet such trend from the public policy because to develop high technology needs a huge basic investment. The high technology policy and its high technology development strategy in a country will show such institutional arrangement.

I. History of High Technological Policy in China and its Technological Innovation Policy

The technological development program as a public policy has been an institutional arrangement to direct the technological development by the Chinese government since 1949. On its history, we may find some background factors in which have influenced Chinese government how to choose its public policy. We could divide the history into four stages.

The First Stage (from 1956 to 1977): the Technological Policy during the Cold War

Institutional background: the term we call it real planning economy with a strong national mobilization ability. During the "First Five-year Plan," China had set up its better industrial capability around the 156 key projects which were supported by former Soviet Union, especially in precision instrument, huge machine and large engineering projects. All of these made China reach much experience.

In January 1956, the Chinese State Council issued "the Long-term Plan of Science and Technology Development in China from 1956 to 1967" (calling it for short "12-year Program"). There were 57 duties and 616 key research projects in it. Especially for fulfilling some top science fields which China were in need of them and had not reached, Chinese government took four measures to resolve it such as to develop computer technology, semiconductor technology, radio electronic technology and automatic technology.

In March 1962, National Commission of Science and Technology issued "the Plan of Scientific and Technological Development from 1963 to 1972" (calling it for short "10-year Program"). Under the structure of the Cold War, for completing the "10-year Program," China government organized the first level researchers and much investment on defense high technological field. It made china reach the atomic bomb technology, hydrogen bomb technology and satellite technology.

Policy evaluation: According to such technological policy, China received a great achievement in its defense technology, such as nuclear weapons and satellite technology. It also set up a high technology research system which was depending on the defense technology.

The Second Stage (from 1978 to 1985): Returning into Civil Technology

Institutional background: During the unstable time after finishing the Great Culture Revolution, China government had not looked for a stable policy direction, and it also was shortage of necessary institutional resource, because it was a time to recover and to adjust both the economic structure and social structure in China. Meanwhile, China government confirmed its basic policy direction of reforming inside and opening outside, and also carried out to transfer science and technology to economic field.

In 1978, the Scientific Conference in China reported "Outline of Plan on Scientific and Technological Development in China from 1978 to 1985" (calling it for short "8-year Program"). In this program, the government pointed out 108 key research projects in the whole country. The most important research fields included agriculture, energy, materials, computer, laser, space science, high-energy physics, genetic engineering.

Policy evaluation: Since "8-year Program" was much free of the China practice situation at that time, it was not carried out and had been readjusted greatly. The 108 key projects had been decreased to 38 ones as national major projects in "Sixth Five-year Plan." In 1982, the Central Committee of Chinese Communist Party raised "The work on science and technology has to face economic construction and the economic construction has to be depending on science and technology." According to this direction which heavily stressed on economy, some scholars pointed out that the government ignored the basic research and defense high technology. From these policies which were not stable, we could find that the China government made its technology innovation policy depending on determining the situation in the World at that time.

The Third Stage (from 1986 to 1996): Combination between Defense and Civil Technologies and Civil Technology must be Play its Leading Role

Institutional background: Influence by the view of New Technology Revolution during 1980s, Chinese government felt a much pressure and challenge on its system from the outside such as America's and Europe's high technology development plans.

In November 1986, both the Central Committee of Chinese Communist Party and the State Council signed "the Outline of Plan of High Technology Research" (calling it for short "Plan 863"). In this outline, China government chose some high technology fields as key research fields which would influence greatly to the economic and social development in the future in China. The technology fields included biological technology, space technology, information technology, advanced defense technology, automatic technology, energy technology and new material technology. In 1995, the Central Committee of Chinese Communist Party made "the Decision to Progress Development of Science and Technology," and also carried out a strategy by "Resurrecting Nation by Science and Education." The Decision stressed specially that "private enterprises are an important part of the whole social system of science and technology development, and also a capability to develop high technology industry." The private enterprises would play a great role as a principle part in technological innovation activity. This was a new position for main part of technological innovation from the property system.

Policy evaluation: Carrying out the "Plan 863," China reached a much achievement in some major high technology fields in the world and set up a basement for high technology industrialization. All of these have kept the economic and social development and the national safe profoundly.

The Forth Stage (from 1997 to present): The Policy Choice according to Marketing Economic System

Institutional background: In 1992, the Central Committee of Chinese Communist Party confirmed the reform aim according to the socialist marketing economy in its 14th Congress and took a series measures to promote the reform process. China has rationally begun to dispose its scientific and technological resources and to set up a national innovation system in which will face to the 21st century.

In 1996, the National Commission of Science and Technology with some other ministries formed "The Outline of Plan for National Science and Technology Research from 2001 to 2010" (calling it for short "Plan S-863"). In 1997, the Central Committee of Communist Party raised a grand development goal to face the new century in its "Fifteenth Congress." In May of 1998, China Science Academy started the experiment to proceed a knowledge innovation project. In August 1999, the Central Committee of Communist Party and the State Council held the "National Conference of Technology Innovation," and made a "Decision to Strengthen Technology Innovation, Develop High Technology and Realize its Industrialization."

In this decision, Chinese government raised that "enterprise is a principle part in technology innovation activity, and technology innovation is prerequisite to develop high technology and realize its industrialization." "We have to take the demand of market, society and nation as a starting point to begin our research and development, and to strength enterprises as a principle part in technology innovation. Nevertheless, we also have to use the market mechanism as essential effect in disposing scientific and technological resources and directing science and technology activity. Thus, it will promote the researchers into market to start their business."

In March 2000, both the Central Committee of Chinese Communist Party and the State Council raised "Some Suggestions to Develop Scientific and Technological Achievements Transfer." It provides a new space to encourage both research and development of high technology and its achievement transfer. The important thing in this document is that the achievement transfer combining with property and capital market firstly in China. This new policy would make the combination between scientific and technological achievement and industrialization with more opening, more socialization and more marketing. It is also an important method to use market mechanism to promote S & T achievement industrialization.

Policy evaluation: Since 1996, China government has tried to make the activity of technology innovation under the marketing economy system, and raised "we have to form a new technology innovation system which is depend on enterprises. Therefore, we could promote the combination among firms, universities and research institutes, and force scientific and technological achievements to transfer a real productivity."

II. The Technology Innovation Policy as a Public Policy

From the modern history in China, there is a logic chain in the Chinese government to make a decision from scientific and technological policy to its high technology policy. Especially its high technology policy as an important part of the public policy has been made by the Chinese government from the foundation to mechanism of decision-making depending on the complicated political and economic circumstances of both home and abroad. And the result of such institutional arrangement was produced by the combination of the history and the present. As a core content of high technology policy, national technological innovation strategy play an important role to create a national technological innovation system which is a result of interaction and coordination between high technology policy and its development strategy. All of these show an important part of public policy in China.

In recent years, making the policy of technology innovation has been based on the idea that "modern high technology development is not only based on the great progress on basic research, but also on the pulling by the demand of society and market." Therefore, the institutional arrangement for innovation activities have to be made the relationship among government, research institutes and universities, firms as a triple state *(Lu Yongxiang, 2000)*.

As a body of management innovation and policy supplying, government inputs into the research institutes and universities the factors such as policy, law and the capital, and to the firms the factors such as information, policy and law. As a body of knowledge innovation, knowledge transfer and talents education, the research institutes and universities input into government the factors such as talents and knowledge, and to the firms talents, achievements and knowledge factors. As a body of technology innovation, management innovation and producing profit, the firms input into the government the factors such as information and tax, and to the research institutes and university capital and demanding factors.

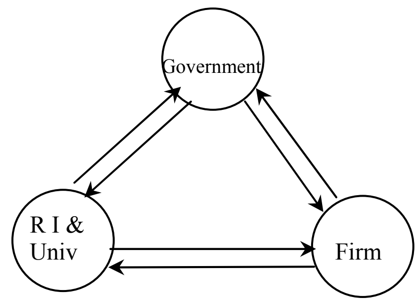

Figure 1 Traditional Tech-innovation Model in China

As different activities of technology innovation and the different stage in the some activity, there are different motive mechanism and its principle. So the government has to deal with them by different method to provide its support, to organize the activity and to evaluate the policy efficiency. For the basic research, strategic research and forward high technology, because of their long circle and high venture and high return for society and country, the government must organize the research term and establish research basements to provide a stable support. National research institutes and research universities are the key research basements on basic research, strategic research and forward high technology exploration. Nevertheless, for the applying research and development, because of their clear direction of demand and market, firms have to play a key role as an investor and an innovator. To concern the conception about technology innovation, the general view is that it is a process of emerging a new product or new craft at the beginning, then through researching, developing, engineering, commercializing and into market finally. Therefore, it is not a simple linear process from research to market. It is rather than a complicated and systematic activity *(Xue Lan and Liu Xielin, 2001)*.

Establishing above triple relationship as a traditional model to form a practice ability of technology innovation, Chinese government started to carry out "Touch Plan" in 1988 which as symbol as technology innovation strategy to realize high and new technologies industrialization, furthermore, it will set up a national technology innovation system. There had been to establish 53 national high and new technology development zones in China since 1990. Such innovation factors gathering by the motivation of innovation policy, Chinese government has tried to let the high technology firms face to market and developed by their technology innovation. It also wants these special zones to become economic development growth poles under a new marketing economy system. To compare with the pulling between by government and by market, because there is not enough of market space in China, the market power is also not enough to combine research institute with firm at innovation activity. Nevertheless, the government has to do such work, and the government behavior is better through public policy. That is the government should set up a service platform or a policy supporting system instead of directive intervening concrete innovation activity. As the figure 2 shows the advanced technology innovation model.

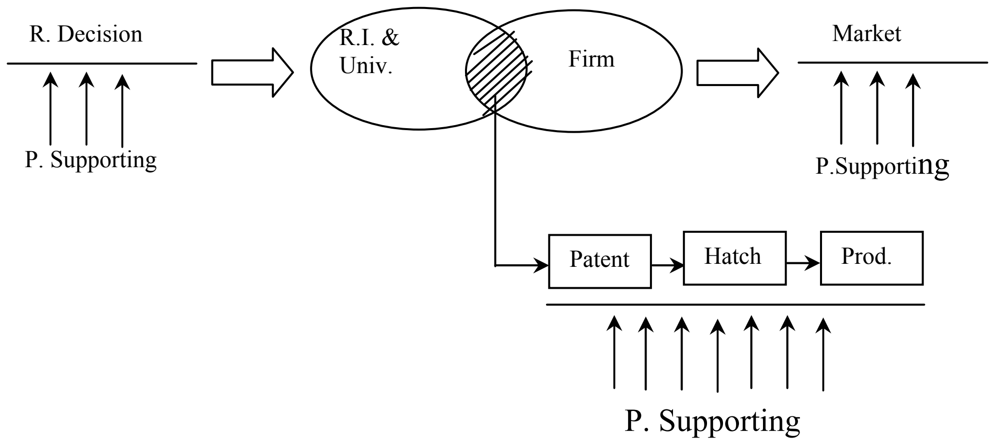

Figure 2. Advanced Technology Innovation Model

According to China situation, we have to agree such view that the government would create a better environment concerning policy, law and infrastructure for enterprise technology innovation. Especially it could effect and rise the innovation efficiency by its concrete policy, regulation, plan, project purchase, protecting knowledge poverty and service (*Xue Lan and Liu Xielin, 2001)*.

As above mention, in August 1999, the Central Committee of Communist Party and the State Council held the "National Conference of Technology Innovation." It was to make clear the direction and the concrete measures for technology innovation, especially on finance policy, tax policy, S & T researchers policy and some other necessary policies. In the fact, there were seven policy documents concerning S & T innovation to the public before the conference, and then a series documents were opened after the conference. They were concerned research institute reform, progressing S & T achievement transfer, S & T award, innovation fund, private S & T enterprises, management institutional reform about research organizations, high and new technology development zone, tax policy, personal policy and so on. All of them showed a more policy space for technology innovation.

III. The Agglomeration Effect in High and New Technology Development Zones in China

To establish such national technology innovation system by the public policy, we have to point out that it is more government behavior. Nevertheless, there are different models and different levels in different province and large city, but all of them promoted the high technology firms in their own area greatly. However, from the practical operation and the results in these zones, they could not compare with Silicon Valley in

America. The agglomeration effect of innovation factors has taken a continuing innovation activities, it is really to learn from the model of Silicon Valley.

The general process to set up a high and new technology development zone is that the local government provides a piece of land and constructs necessary infrastructure, then makes some advantage policy such as for attracting talents, tax reduce, management and so on. All of these only attract more universities, research institutes and firms to arrive there. From the policy direction, establishing a high and new technology development zone was planned by efficient agglomeration of innovation factors, then to form an information exchange platform and to set up a necessary learning network. Chinese government considered that would save internal cost for a continuing innovation activity in the zone.

The high and new technology development zones consist of an important part of national technology innovation system. The national technology innovation system is an organization and institution network by public and private parts in a nation which will create, spread and use new knowledge and technology. The innovation policy under such system will stress cooperation between different enterprises or between enterprise and public research organization. It also stresses the important meaning to progress further innovation in a firm and establish a partnership with government.

Such national technology innovation system in China is according to marketing economy regulation and WTO principles, and it also a system which will adjust Chinese economic structure strategically to fulfill various demands for technology development. It has to be a capability to absorb and apply scientific knowledge in the World and a knowledge storage system. Finally, it is an innovation system which will support Chinese economy development in advance in the future *(Li Xueyong, 2002)*.

From the public policy evaluation, whether or not an economic and technological development zone is successful by promotion of the technology innovation policy, it is not completely to get an answer from traditional agglomeration theory which only emphasizes to save the investment. It should be understood from the output in which could provide larger profit for a firm. In such gathering zones, there is much potential profit space for a high technology firm. It could get some innovation benefit from an internal learning network in the zone. Meanwhile, we have to point out that there is also much risk, and this is a choice for an opportunity cost for a firm to consider. A good technology innovation policy should explain such opportunity cost.

Difference from the situation in China, American Silicon Valley has formed an innovation culture in which has been never directed by a public policy. However, China has indeed the concrete technology innovative policy to establish a special innovation zone. Public policy has played a great role in Chinese economic development, and so does technology innovation policy in agglomerating innovation factors. It is an institutional arrangement under present social structure in China. The reason for such institutional arrangement is that public policy is playing a role to make up the shortage of marketing system in China. Such shortage we call it soft factors to support innovation activity. Nevertheless, the soft factors have been in its original culture in American Silicon Valley. As some scholars pointed out: "It is necessary to set up a regional innovation environment for a successful high technology complex. To produce more and more complicated high technological products needs an industrial mixing together and overlapping propagation. The knowledge innovation and its pooling only take place in a good environment" *(Wang Jici, 2001)*. "The emergence of Silicon Valley in America depends on its unique enterprise culture besides structure productive factors (such as information, venture capital, high quality labor). And a "group enterprises" has been formed in their working place, bars and restaurants which we call it culture network. All of these have been a basic factor put its innovation environment developing" *(Castell & Hall, 1994)*.

IV. Case Study: Haidian Scientific and Technological Park

Along the history of policy-making of high technology in China, we have to criticize objectively the high technology policy from the mechanism of public policy, and research the technological innovation strategy and the national technological innovation system seriously. The focus research is on how the inventions from public research organizations transfer to technological innovation in the national technological innovation system. Between the technology invention as a public good and the technology innovation as some commercial value, the Chinese government how to play its suitable role by its high technology policy. Meanwhile, we also discussed the pooling and transferring between institutional resource and technological resource in the high technology field and the combination of the arrangement between micro-institution and macro-institution in its high technological innovation system. Based on the theory of the public policy, the author evaluated the national technological innovation system in China. If we want to get a clear answer, we have to research Haidian Scientific and Technological Park as a case study.

Haidian Scientific and technological Park is located in Haidian district in Beijing. It is a most successful one among 53 national high technology development zones in China at present. And it has two advantages to locate in Haidian District. One is a high quality human resource in this area. Haidian District gathers the most densely intelligent resource in China. There are 73 universities such as most famous Hsinghua University and Beijing University, 232 research institutes concentrating around China Science

Academy, 60 key national laboratories and engineering research centers. Another advantage is its market. Gathering researchers and scientists takes a demand of high technological products, furthermore, it becomes a largest distributing center for electronic products.

From the history, Haidian District was planned according to former Soviet Union mold as a culture and education area in Beijing before 1980s. During the period of planning economy system, even there were so many research institutes and universities, but the system made the S&T achievements separate from economic development. At the beginning of 1980s, the policy of reforming inside and opening outside influenced greatly in this area. Many private enterprises started their business from dealing with trade and technology service. This was a new try to develop high and new technology industry beside the old system. Therefore, they got the government policy support until 1988. At that year, Beijing Haidian New Technology Experiment Zone was formed by the core of Beijing University, Hsinghua University, China Science Academy and "Electronic Street." Haidian S&T Park chose the management model as "small government and much service" which lead it on a rapid developing road. Table 1 shows some statistic data of Haidian S&T Park since 1988.

Table 1 The Development Speed of Haidian S & T Park

Year	1988	1993	2000
Number of Enterprises	400	1300	6800
General Income (100 million yuan RMB)	7.0	37.0	1060.0
Industrial Output(100 million yuan RMB)	4.8	12.0	660.0
Tax (100 million yuan RMB)	0.25	1.5	36.0
Export (100 million us dollar)	0.03	0.45	7.5

Data source: Haidian S & T Park in Zhong Guan Cun S & T Zone, "Enterprise Culture both Home and Abroad", February, 2001

From above statistic data, the development speed of Haidian S&T Park is tremendous. Its general income, industrial output, tax and export increase as many times as the number of enterprises increase. This shows that the scale of firm in the park increases rapidly, and especially such trend has been obvious after 1993. The background is that China government confirmed the direction of socialist marketing economy at that year.

During the construction of the park, with more and more marketing effect, the Management Committee of the park has gradually enlarged its government service capability and set up its service platform. All of these are to create a good environment to develop high technology industry, and make the potential resource become socialization by further emerging regional resource. The Management Committee has done two kinds of work to set up the government service platform.

Firstly, the Management Committee specifically carried out preferential policies about technology innovation both from the nation and Beijing. Therefore, it made the policy resource combine with intelligence resource and human resource to form a motivation for technology innovation. The preferential policies include 7 items about attracting talents, 13 items about capital and tax and 10 items about management reform. To carry out such policies progress the investment environment and the innovation environment in the park.

Secondly, the Management Committee has positively developed organization of service agencies. This is a strategic choice to breed market mechanism and make the government withdraw from directive interfere innovation activity. Therefore, the government would use policy measures to establish service system and to realize its aim of "small government and large society." During the early time of the park, the local government encouraged to found Beijing High and New Technology Enterprises Association and Beijing Foreign Investor Enterprises Association. Both the two associations have played the great role to establish the relationship among enterprises, between enterprises and society and between enterprises and government. The membership of Beijing High and New Technology Enterprises Association is 1830, and it takes place more than 100 of various lectures, training and guidance every year. In March of 2000, the association opened its web site "Zhuxin Net" (www.htea.net.cn). This web site provides much information service for the enterprises in the park. The membership of Beijing Foreign Investor Enterprises Association is more that 1000. It has played its role in attracting foreign investment, making foreign investors understand the park and serving to foreign enterprises.

Haidian S & T Park takes place "Zhong Guan Cun Computer Show" every year. It is also an important activity to set up government service platform and to combine various resources. The "Show" is a surface to contact on the regional resources. For example, there is a S&T achievement exhibition of 16 universities in the show which provides a place to understand among universities, research institutes and enterprises. Then they will discuss the details such as cooperation. The further development for Haidian S&T Park is urgent to replace the resource in universities and research institutes to put into industrial development. The "Computer Show" by the Management Committee could meet such demand.

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