B. Creation of Innovation: Research Centers, Institutes and Universities

Cooperative R&D Agreements and R&D Collaboration between Firms and Public Laboratories in the United States

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I participated in the first of these meetings in Beijing. And it's a real pleasure to see some familiar faces here. My topic today deals with a particular federal policy instrument known as Cooperative Research and Development Agreements, or CRADAs, as they are known in the Washington language that loves acronyms. And what I want to talk about is some research of mine and a little bit of research of others that has attempted to both describe the outlines of this form of collaboration between federal, public laboratories in the United States and private firms, and then present a little bit of information from some case studies that a couple of students and I have done on the operation of these Cooperative Research and Development Agreements.

1. What are CRADAs?

As Lewis Branscomb pointed out this morning, the funding mix in the U.S. national R&D system has shifted quite significantly in the last 20 years. In the early and mid-1960s, about 1/3 privately funded R&D and 2/3 publicly funded R&D comprised the national R&D budget. But in the 90s, the ratio is reversed: about of national R&D is 1/3 publicly funded and 2/3 privately funded.

The United States still maintains a very large network of public laboratories, many of which are operated by contractors. In some cases universities, for example, the University of California serves as the prime and prominent contractor (for Los Alamos and Livermore Laboratories). This network of public laboratories accounts for something on the order of 15 to 20 billion dollars in annual expenditures within the U.S. R&D budget. This is a very large component of the publicly funded U.S. R&D infrastructure. It has been the focus for many years of considerable congressional and executive branch interest, both in terms of improving the efficiency of operation of this complex and also certainly during the 1980s and 1990s, utilizing this complex of publicly supported research labs to improve civilian or private sector innovative performance. This is where the Cooperative Research and Development Agreement comes in.

The CRADA was created in 1986 in the Technology Transfer Act of 1986 and was extended in 1989 to cover what are known as GOCOs, another acronym, Government Owned Contractor Operated federal laboratories. CRADAs have a key component to allow for collaboration between public laboratories and private firms in joint research and development, and they allow the private sector participant to receive the intellectual property. So the CRADA instrument shares with Bayh-Dole Act, one characteristic that one of my collaborators, Bhaven Sampat, will speak about in a few minutes -- the emphasis on clarifying, refinancing, and transferring the government's intellectual property rights.

CRADAs allow for the transfer and assignment of the intellectual property to the private sector participant, with government retaining a paid up, non- exclusive license to that intellectual property. But in some cases, federal agencies have contributed to the federal laboratory a share of project costs by allowing specific allocations of funding to the federal laboratories participating. CRADAs assumed considerable prominence in the discussion and debate over new approaches to U.S. science and technology policy in the 1990s, both because they seem to offer the prospect of improvements in collaboration between public and privately funded research, and because they offered in some cases a vehicle for shifting and exploiting the capabilities of some laboratories that were formally almost exclusively devoted to military research and development. The expectation was that CRADAs would shift some of the government's research activities to those that would benefit the civilian economy and also might offer the prospect of improved innovative performance at relatively low direct costs.

2. What do we know about CRADAs?

US Department of Energy subsidized CRADAs at nuclear weapons laboratories during the early 1990s as part of "defense reconversion," making the capabilities of military labs available for civilian innovation.

What do we know about CRADAs? Surprisingly little. The Department of Commerce published an excellent summary of what is known about the effects of Cooperative Research and Development Agreements in 2000, a report entitled *Making Partnerships Work*. But even that report, which draws on essentially all of the available data recorded by agencies operating CRADAs, provides relatively little information. We really don't have much information, for example, on whether CRADAs are important in terms of the amount of public money devoted to them. We do not know much about their effects on private firms' innovative performance, the alternative mechanisms for encouraging private innovation, or more general types of licensing or innovative activity within the public labs. There are some empirical studies. One by James Adams of the

University of Florida found that "CRADAs are important sources of innovation." These laboratories appear to be more innovative than the firms they work with based on their rates of patenting, but what we don't know is what is cause and what is effect. Are these laboratories more innovative, because of their use of CRADAs, or do they use CRADAs because they are more creative?

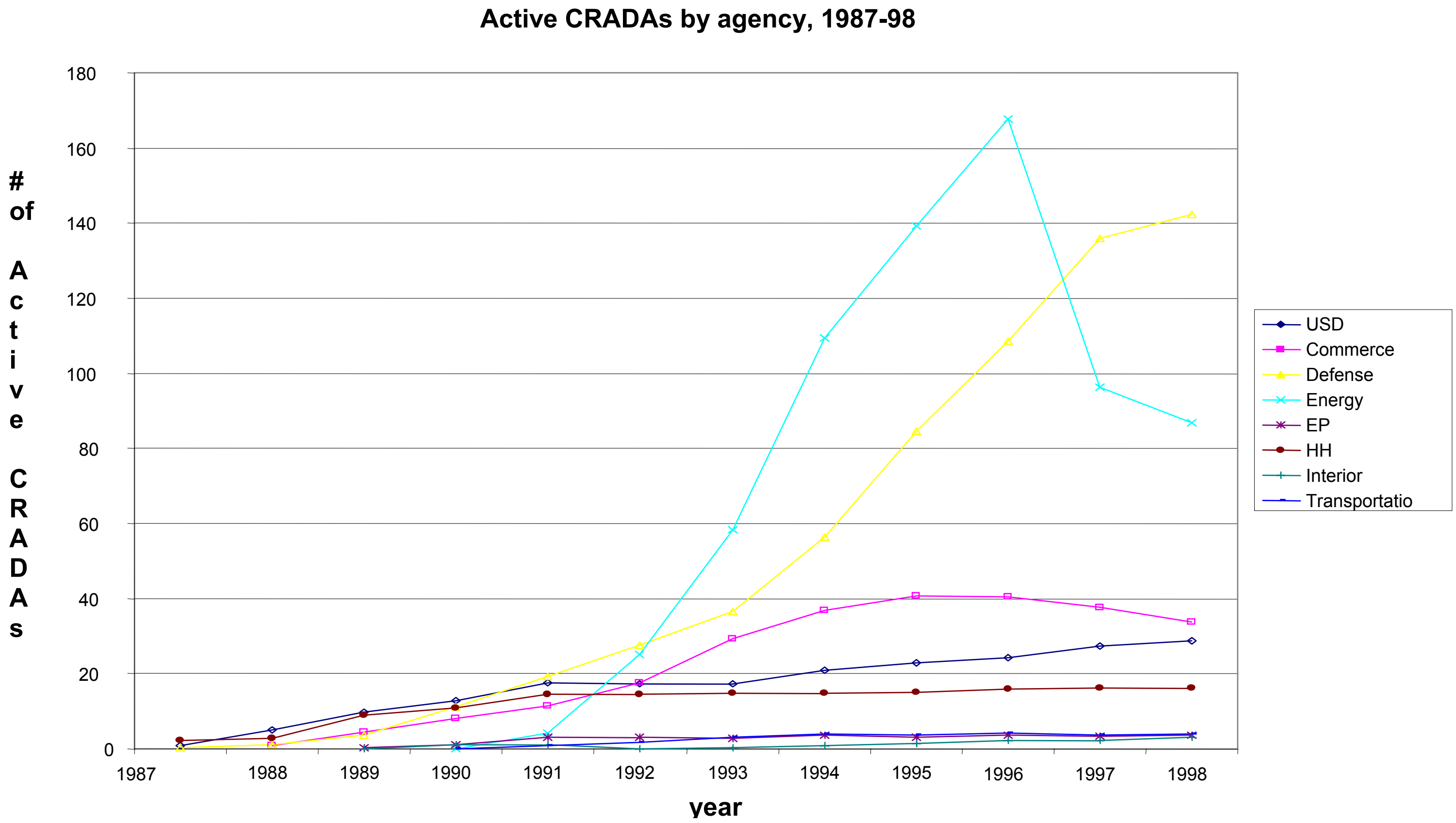
3. Data on CRADAs

So there's a real question about the effects on private sector innovative performance of participating in CRADAs. CRADAs have grown substantially in number during the past 10 years. Active CRADAs have grown from 34 in 1987 to more than 3200 in 1998. And interestingly, they account for a considerable expenditure of public funds, at least in the data that are available. For example, the Department of Energy (DOE) provided direct support for its laboratories' participation in Cooperative Research and Development Agreements more than one billion dollars during fiscal years 1993 to 1998. That is more than the federal government was spending on the Advanced Technology Program during this period. The DOE is one of many departments and agencies, although one of the most important participants in Cooperative Research and Development Agreements, as I'll show in just a couple of minutes.

A further interesting issue here is how the National Science Foundation reports information on Cooperative Research and Development Agreements. In its most recent, very authoritative, very thick volume on *Science and Engineering Indicators* incorrectly claims that patenting and licensing by federal agencies are attributable entirely to CRADAs. Federal agencies' invention disclosures come from many sources other than CRADAs, the NSF statement notwithstanding.

The National Institutes of Health, as most of you know, is a very large, federal, basic science funding and performing agency. It generates patent applications from its non-CRADA activities at the same rate as it does from its CRADA activities. This gives you a sense of the CRADA activity during the '87 through '98 period.

The important breaking trend here is associated in many peoples' minds with the change in political control of the U.S. Congress in 1994 from the Democrats to the Republicans. There was rapid growth in active CRADAs from FY 1987 through, roughly, fiscal year 1995. Then there was a sharp tailing off, partly related to Congressional control by Republicans, who expressed skepticism about the role of CRADAs and in particular about the appropriateness of federal financial support for collaborative R&D activities with private firms.



This figure shows CRADAs by agency; the blue line is the Energy Department. And as you can see, the Department of Energy was really one of the most important negotiators and operators of CRADAs until this sharp break in roughly 1994-95. The yellow line here is the Department of Defense, whose use of CRADAs has continued to grow. Other agencies, the Commerce Department, Health and Human Services, (which is substantially the National Institutes of Health), and the Transportation Department, the US Agriculture Department are shown. So you can see that Energy and Defense are the two leading negotiators and users of CRADAs. They are the two agencies with the largest networks of publicly funded federal laboratories. But even in the case of the Department of Energy, there has been a sharp tailing off in the late 1990s in the number of CRADAs operated.

4. Missing Data about CRADAs

The Commerce Department information, which is as comprehensive as any assembled in the federal government, omits a number of important pieces of information. These are not readily reported to the Commerce Department. We don't have much information, for example, on the number, the industry mix, and the size of firms participating in individual CRADAS all by agency. So we can't really compare across agencies on the structure, the composition, of individual cooperative Research and Development Agreements. Similarly, we don't have much information on the mix of participants from different backgrounds of firms and universities. The number of licenses and patents specifically flowing from CRADAs, as opposed to all agency R&D activity are not reported in a very meaningful way, and we lack good information on the death rate -- the number of CRADAs that are terminated prior to their schedule for completion. And as a result, we don't have very good data that would support the kind of comprehensive assessment of CRADAs that I think is quite important and overdue given their prominence in the political rhetoric.

5. Two field studies of CRADAs operated by the US Energy Department

Based on the limited data, some students and I went out into the field and tried to do some case studies of individual CRADAs. It's important to understand that this is a particular slice of what is a very large area of activity in any agency. So these are CRADAs we studied were operated by the U.S Energy Department through its network of laboratories. In one case these CRADAs were operated by Lawrence Livermore National Laboratory, which is operated by the University of California for the Department of Energy and historically has been a nuclear weapons research facility. We looked at five of these CRADAs, ranging in budget from one to 20 million dollars and involving private firms of very diverse

5.1 Summary of Ham-Mowery findings

What do we find in the first of these studies? This figure shows the study of five CRADAs operated by Lawrence Livermore and again these were agreements that were by and large negotiated in the early '90s. Some of the issues raised by these CRADAs have been overcome in subsequent revisions and policy and operations. Other problems, though, are more endemic to this particular instrument. Most of the private sector participants and certainly almost all of the laboratory participants agreed that the public laboratory had capabilities, equipment, and facilities, many of which had been developed over nearly 50 years of investments of public funds that were unique, that would be very difficult to find elsewhere. However, some issues arose, in particular, because laboratory research directors and senior researchers saw CRADAs as a vehicle that could bring in funding for their group. That is to say, if you successfully negotiate an R&D agreement with a private firm, you can get additional funding from Washington D.C. through the subsidy arrangement. This creates incentives for researchers to negotiate Cooperative Research and Development Agreements. That's the intention, in part, of the public funding undertaking. But it also creates particularly strong incentives for researchers working with and seeking to involve small firms. Firms with relatively limited technical capabilities are frequently oversold. Promises were made of both access and capabilities and commercialization possibilities of collaboration that were probably unrealistic.

A second problem related to the relatively rigid policies governing the flow of resources, the expenditure of resources, and the costs of the R&D performed in the lab under the CRADA, that made it very difficult in many cases to change the scope of projects. That often limited access by firm personnel to senior laboratory personnel. Other issues in the negotiation and administration of the agreements also complicated their operation. The emphasis on intellectual property often required very complex lengthy negotiations at the outset of these agreements that really delayed their inception and complicated their operation. This was true in particular for some large-firm Cooperative Research and Development Agreements, because, in many cases, these large firms brought significant intellectual property to the table. So even in situations where perhaps the firms were not centrally interested in gaining title, or license, to government patents, they felt that they had negotiated elaborate arrangements for intellectual property. Those negotiations took considerable time. These delays in project approval related to intellectual property negotiations had significant effects because funding and the inception of these projects could not begin until the negotiations were completed.

Finally, it was very difficult to ramp down these projects gradually in many cases. It was very difficult to support the kind of iterative, interacted activity that Dr. Branscomb mentioned as particularly important in transitioning a particular technology from the laboratory into a manufacturing environment, because there was a termination date, and the funding was stopped immediately upon that termination date. Firms had a great deal of difficulty maintaining access to laboratory researchers and personnel after the funding had been cut off, because the laboratory personnel, in effect, could not fund themselves for these activities after the end of the project.

There were also issues relating to understanding by laboratory personnel of the requirements of the firm and understanding by the firms of what was necessary in order to collaborate with a large, sophisticated public research organization. Again, keeping in mind that the Livermore personnel had in many cases spent years and years working on military and defense projects. There were important differences, they discovered, over both the nature of the requirements for the R&D being performed for civilian markets and, in particular, the needs of these customers, these collaborators, for cost effective rather than high performance technologies.

And you have a real difference, obviously, in the requirements of commercial firms for cost competitive solutions that differ significantly from the sorts of public sector customers that these researchers had been working with for many years. This is a common problem in many cases of public sector researchers and research laboratories shifting from military to civilian technology missions.

The second problem related to the ability of the small firms to keep up with, to manage, and to absorb the technologies being developed by Livermore Laboratories. There is a serious challenge for these small firms in many cases -- simply of inward transfer of the results and exploitation of the results of this collaborative research. Small firms, in particular, found this in many cases to be far more difficult and far more costly than they had expected.

Conclusion from the first case study

So our conclusion from the first of these studies was that CRADAs are useful, but not ideal for all types of R&D collaboration. Their inflexibility limited their effectiveness and in particular, they raised complex challenges and issues as they were used for collaboration with small firms. Both this issue of absorption and also the problem of small firms needing assistance in many cases in many areas going beyond the purely technological, needing assistance in marketing, in management, and in other areas, areas in which these researchers in many cases had limited expertise.

5.2 Summary of Linden

That second project, case study which I'll summarize more briefly here is a project dealing with what's known as extreme ultra-violet lithography, an important production technology for the semi-conductor industry for the next decade. Here you have a group of very technologically sophisticated firms, collaborating with a network of public laboratories on a very different basis. Here, the public laboratories' funding is coming almost entirely from the private sector partner. So they are operating much more as a contractor. This, in turn, improves flexibility and it reduces the incentives of lab personnel to oversell their capability. Where the participating firms are large and have substantial in-house capabilities, their collaboration and absorption of the results has been easier. The project is much larger in scale than the projects that we studied in the previous case studies and now obviously improves access by these firms to senior lab personnel.

Nevertheless, this CRADA also has faced important challenges, although challenges that are slightly different, I think, in character than those associated with the earlier case study. Foreign firms, Nikon and ASML, respectively a Japanese and a European equipment firm, have sought to participate in this CRADA. That has been very controversial because of the role of publicly funded infrastructure, if not public funding of this project. Intellectual property remains a very complex issue, because of the fragmented and widely distributed ownership of this intellectual property among the various participants and among firms who are not directly participating in this. Semiconductor manufacturing equipment firms are going to be the primary actors in commercializing the results of this Cooperative Research and Development Agreement, but their current role in the agreement is fairly limited. And in many cases, these equipment firms, especially the U.S. firms, are much smaller and the capital requirements of absorbing and commercializing this technology are quite substantial. So the hand-off of the technology from this Cooperative Research and Development Agreement to the equipment firms, a hand-off that is necessary in order to commercialize this technology, remains a real challenge. I think you can see some issues here and really a dilemma for U.S. policy makers that is also present in many types of collaboration between large public laboratories and private firms.

The dilemma is the following. It's much easier in many cases for these laboratories to collaborate with large technically sophisticated, relatively well funded private sector firms. At the same time, the mission of these public laboratories in many cases is to serve a broader public good, a broader set of goals that really results in a strong mandate, or shall we say, strong instructions from political overseers to reach out to smaller firms. And those firms are in many cases much more difficult to work with for any public sector laboratory, let alone a laboratory with a substantial history of focusing on military R&D. So you've got a real trade off here between the small firm, complex outreach, broader set of services that are needed by many of these small firms and the easier, but perhaps less politically attractive of working with established large firms.

I think that we need a better set of criteria both for assessing where CRADAs are appropriate and inappropriate and for evaluating and monitoring their progress. The subsidies for CRADAs, I think, very much operate as a two-edged sword, if you will. In some cases, they facilitate, and in other cases, they complicate their operations. The role of intellectual property rights in CRADAs again makes them an instrument that can be very difficult to operate, rather than necessarily facilitating their goals of commercializing and supporting public/private collaboration. This is partly because of the complexities of negotiations over intellectual property rights and partly because of the fact that many participants are not always centrally concerned with intellectual property rights.

Delays in the negotiation and inception of CRADAs created severe problems. I think we need a better set of criteria about where these CRADAs make sense and where they make less sense. Within the Energy Department projects, particularly the first set of five projects that we looked at, Energy Department lab managers devoted far too little attention to evaluating and improving administration of CRADAs and in particular, trying to monitor the operation of these CRADAs in real time, trying to assess whether they were working effectively while they were under way.

These laboratories also had done very little to do retrospective studies and evaluations of what worked and didn't work in the Cooperative Research and Development Agreements they had experience with. They're losing a very important source of information on effective collaboration. So I think one very important guideline here is even if your managers may have limited understanding of how to operate these agreements, while they are under way, I think it's very important to encourage particularly public laboratory managers to try to do some retrospective assessment and evaluation of projects shortly after their completion, termination, or interruption. This adaptation of military laboratory personnel to civilian projects and applications obviously is a significant challenge.

The subsidies issue is one that remains complex, because it really goes to the heart of this dilemma that I mentioned about how these public sector organizations should be used to meet their goals as entities that are supported with public funds.

6. Conclusion

The conclusions of my paper are as follows:

CRADAs, like a number of other US technology policy initiatives of the 1980s and 1990s (e.g., Bayh-Dole), assign a central role to the negotiation and transfer of formal intellectual property rights. But industrial participants often are not concerned with intellectual property rights. Negotiations over IP rights can impede the timely inception of the CRADA.

Delays in inception of CRADAs have created severe problems.

CRADAs may be effective for some but by no means for all forms of collaboration between public laboratories and industrial firms but they often are less effective for small firms.

Finally, of course I'm sounding very much like an academic, we continue to have very little data collected on a comprehensive basis across the many federal agencies that sponsor CRADAs, that really allow us to undertake more of a detailed assessment and the kinds of evaluation that would enable us to improve and enhance the operation of these projects going forward.

This remains a very important instrument of federal technology policy. It's obviously an instrument of policy that has important implications for other economies seeking to develop and utilize large public sector R&D establishments, but we still really do not know that much about the operation of these agreements within the United States. And I think therefore emulating or learning from these policies elsewhere is something that should be undertaken with great caution.

I've simply presented a few case studies here. These case studies are drawn from a single agency. They cover a limited period of time. Therefore I think that caution is very much advisable in drawing conclusions for application of a CRADA-like policy elsewhere. But I hope that we will collect some more information on the operation of CRADAs in the United States that will make this both more effective in the United States and perhaps more useful as a learning opportunity for other nations.

The Impact of R&D Institute Reform on Technological Innovation in China

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I. Introduction

China economic reform has experienced the process from reforming micro operational mechanism to reforming allocation system for resources, and finally to setting up socialist market economy system of China. At the same time, the Chinese Science and Technology System Reform (CSTSR) has experienced the process from extending decision-making power of R&D institutes to reforming R&D funding system, gradually to introducing the market mechanism into science and technology system and making some progresses in science and technology legislation, finally to setting up new Science and Technology System, which is in favor of the Science and Technology Development, of the integration of S&T and Economy, so as to promote economic development. In Short, the purpose of CSTSR is to serve national economic development.

During the past years China government has made a serial of policy measures to promote the CSTSR. On one hand, the State Council makes the “Decision for Deepening the Reform of Science and Technology System During the Period of the Ninth Five-Years Plan” to advocate that scientific research institutes can be oriented to economic construction by: (1) joining in enterprises as technology development organization of the enterprises or an industrial sector; (2) operating according to the operational mechanism of corporations; (3) setting up enterprises or becoming an enterprise; (4) becoming technological service organization. On other hand, Chinese central government approves the “Knowledge Innovation Program” (KIP) proposed by the Chinese Academy of Sciences, with a view of setting up National Innovation System. Both the State Council’s Decision and KIP have profound impact on CSTSR. In this paper, I mainly deal with the impact of scientific research institute reform on technological innovation in China, specifically the transformation of 242 State-owned R&D independent research institutions (IRIs) affiliated on the Ministry of Economic and Trade, and the reform of 123 state-owned R&D IRIs affiliated on the Chinese Academy of Sciences (CAS).

II. The Transformation of 242 State-owned R&D Research Institutes

The Transformation

One of the main purposes for system reform in China is to set up socialist market economy system, namely to change the existing planning system and building a market-based system, so as to be in the top 10 most S&T competitive nations by 2010. After 20 years incremental reform on operational mechanism with a view to strengthening the linkage between production and research, for example, to decrease government budget for applied R&D institutions gradually so as to force them to survive in the market, and to encourage R&D institutions and university to exploit the economic value of S&T research by setting up their own companies, Chinese Government decides to withdraw from some competitive sectors and take some radical reform measures.

In 1998, the State Council decided to abolish 10 ministries (including the Ministry of Machine Building, the Ministry of Metallurgy Industry, the Ministry of Coal and so on) with view of increasing the power of market in resources allocation. Meanwhile, the transformation of 242 R&D institutions affiliated to above ten ministries becomes one of the key issues concerning the Reform of Science and Technology System in China. The 242 R&D institutions consist of about 115,000 staffs (about 12.3% of total staffs of research institutions affiliated to ministries) in 1998, 63,000 of which are scientific persons (about 10.7% of total), 43,000 of which are Scientists and Engineers (about 11.9% of total).[1]

On 22 Feb. 1999, the Ministry of Science and Technology, the State Commission of Economic and Trade, the State Commission of Development Planning, The Ministry of Finance, and other two government agencies made the decision that all 242 R&D institutions should be transformed completely by the end of June 1999 with a view of moving away the barrier between research and production. The goals of the transformation are to strengthen the linkage between Science & Technology and Economy by deepening Science & Technology System Reform and accelerating the building of technological innovation system, in which corporations are principal part. The transformation could strengthen the institutional competitiveness and promote the industrialization of science and technology achievements so as to serve national and regional economic and social development.

How to transform? As mentioned above, the transformation of state-owned R&D institutions into enterprises could choose four models, namely: (1) joining in enterprises

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[1] The Ministry of Science and Technology: China Science and Technology Indicators, kexue jishu wenxian chubanshe (Science & Technology Documents Press): Beijing 2000, p.60.

as R&D center; (2) operating according to the operational mechanism of corporations; (3) setting up enterprises or becoming a self-supporting enterprise; (4) becoming technological service organization.

In order to promote the transformation of the 242 R&D institutions, Central Government provides transformed institutions with following preferential policies concerning taxation, loans, subsidies and personnel, including:

- to provide operation funds for transformed institutions as before；
- free income tax from 1999 to 2004 for transformed institutions;
- to permit transformed institutions to do self-supporting Imports & Exports;
- to allow transformed institutions to take on National Science and Technology Programs, which are open to State-owned R&D Institutions; and
- to enjoy other preferential policies for Science and Technology Company.

In practice, the 242 state-owned institutions had been transformed by the end of 1999. 131 of them join in enterprises (group), 40 of them become local self-supporting enterprises, 18 of them become technological service organizations, and 29 of them were transformed into 12 large self-supporting science and technology enterprises owned by central government.

The Impact of the Transformation

The transformation of the 242 R&D institutions has profound impact on the technological innovation in China. The transformation of the 242 R&D institutions is an important breakthrough of national reform of Science & Technology System, which has very important demonstration effect for transforming other scientific institutions. In practice, 134 R&D institutions (about 50,000 staffs) affiliated to other ministries such as the Ministry of Construction, the Ministry of Railway, the Ministry of Communication, and the Ministry of Information Industry, had been transformed into enterprises by the end of 2000. Meanwhile, about 5,000 local government-owned R&D institutions follow this model too, namely to be transformed into enterprises. Last year, Central government began to transform state-owned public welfare research institutions, but in different way to some extent.

The transformation of the 242 R&D institutions strengthens the linkage between R&D and production, and to some extent the technological innovation capability of enterprises. The share of researchers in state-owned independent research institutions decreased from 52% of total R&D persons in China in 1987 to 30.2% in 1998[2], the share of Scientists and Engineers in state-owned independent research institutions decreased from 31.5% of total in China in 1991 and 21.5% in 1999.[3] The share should be much lower than before as soon as all state-owned independent research institutions have completed the transformation. The fact that the share of R&D persons in state-owned independent research institutions has been gradually decreasing also implies that more and more R&D personnel join in industrial sectors. Enterprises are gradually becoming the principal innovator, investor in R&D.

The transformation of the 242 R&D institutions is propitious to exploiting human creativity of researchers, and to building up indigenous technological innovation capability in the transformed institutions. On the one hand, the transformed institutions are forced to build indigenous continual innovation capability due to increasingly drastic market competition so as to develop competitive hi-tech products and to win the competition; on the other hand, the fact that technology and management expertise participate with other production factors (such as capital labor and land) in distributing the economic returns of the transformed institutions must prompt researcher to exploit new technological resources, and to make full use of them.

The transformation has changed the research model of these R&D institutions from government-oriented or following foreign research organization to market-oriented. Although R&D institutions are encouraged to run business for about 20 years, but performance of researchers is still evaluated according to academic indicators such as academic papers and experiment results, not the economic value of research results. The purpose for R&D institutions to run business is to make money so as to survive, not to meet the technological demands of enterprises. As soon as these R&D institutions are transformed into enterprises, to maximize profit, the nature of enterprises, will push transformed R&D institutions to develop what market need and quickly commercialize them. Besides, the transformation itself also provides many opportunities for the combination of technology and capitals, which could enable transformed R&D institutions to enlarge their market share.

Obviously, the transformation of the 242 R&D institutions has some negative impact on technological innovation capability in China.

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[2] Liu Xielin: The Road towards Innovation: --The Reform of China's Scientific and Technological System since 1980s, ***Proceedings of Sino-German Symposium on Technological Innovation and Management,*** Qingdao China, May 28-29, 2001.

[3] The Ministry of Science and Technology: China Science and Technology Indicators, kexue jishu wenxian chubanshe (Science & Technology Documents Press): Beijing 2000, p.57.

First of all, the model of the transformation is too simple, and neglects the diversity of institutes in nature and the variety of social economic demands. In practice, most of 242 state-owned independent research institutions have been transformed into state-owned enterprises, which still need to be transformed into modern corporations or companies with mixed ownership so as to overcome the problems such as low efficiency that state-owned enterprises usually have to face. However, the technological innovation capability of enterprises in general is still weak.

Secondly, some of these institutions provide public goods for industrial sectors, not for specific enterprises. They can not obtain enough economic returns from market to support themselves. It is worthwhile to point out that China is still a developing country, which implies that most Chinese enterprises are weak in technological innovation, and small in business scale (compared with world leading multinationals). They need new technology but have no technological capability to develop them. Furthermore they can not afford to invest large amount of money in R&D even if they realize that R&D is extremely important for their competitiveness. These kinds of technologies should be provided by government-supported institutions or non-profit organizations. In this aspect, the technological innovation capability of some industrial sectors in China is not strengthened, but impaired. Perhaps some institutions should be transformed into non-profit organizations so as to draw and integrate social resources for R&D.

Thirdly, some preferential policies to promote the transformation have to be adjusted or even abolished after China's entry into WTO. For example, these transformed institutes are no longer R&D institutes, but still treated as state-owned R&D institutions. The experiences drawn from the transformation of 242 R&D institutions (later 134 R&D institutions) play a very important role in guiding the transformation of state-owned social commonweal research institutions.[4] In practice, some of these institutions mainly provide public goods to the public. They can not obtain enough economic returns from their research in the market and need government supports. Some others could support themselves by providing public service. Therefore, Central Government approves that part of state-owned social commonweal research institutions can be transformed into Non-profit Scientific Organizations; most of them should follow the transformation model of 242 R&D institutions. In order to promote the transformation of state-owned social commonweal research institutions, the Ministry of Science and Technology, the Ministry of Finance and other two government agencies[5] promulgate the "Some Notions

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[4] There are about 290 state-owned social commonweal research institutions affiliated to central government agencies. These institutions consist of about 51,000 staffs.

[5] The Ministry of Science and Technology, etc.: "Guanyu fei yinglixing keyan jigou guanli de ruogan yijian" ("Some Notions about the Management of Non-profit Scientific Organization", 2000.

about the Management of Non-profit Scientific Organization," which fills the gap in the framework of current laws & regulations and makes it possible to transform some state-owned social commonweal research institutions into Non-profit Scientific Organizations.

III. The Reform of Chinese Academy of Sciences (CAS)

Since June 1998 CAS has carried out the pilot project of the national Knowledge Innovation Program (KIP) which was launched by the Chinese government with a view of establishing national innovation system and promoting science and technology (S&T) progress. The implementation of KIP shows that China's political leadership is placing high priority on innovation as a key element in its transformation into a market-driven economy. During the initial phase of the pilot scheme (from1998 to 2000) of KIP, CAS has made great efforts to adjust its disciplinary layout, restructure its organization and carry out reforms on its operational mechanism. Since 2001 CAS begin to implement the second phase of the pilot scheme (from2001 to 2005) of KIP. The goal of the reform in CAS is to establish about 80 national research institutes with powerful S&T innovation capability and sustainable potential, 30 of which are distinguished research institutes in the world, three to five of which are the first class research institutes in the world.

The Reform in CAS

In the aspect of the disciplinary readjustment, CAS gives high priority on the fields of mathematics and systems science, matter science, astronomy, earth sciences, informatics, high-performance materials and advanced manufacturing, resources, the environment and sustainable development, life sciences, bio-resources and bio-diversity protection.

In line with the principle of reducing low-level repetition and encouraging interdisciplinary studies, CAS undertakes the most extensive organizational restructuring it has ever made. By the end of 2001, a total of 69 CAS research affiliates, after undergoing some drastic reforms, have gain the access to the KIP, which means preferential policy treatment as well as strong financial support.

Based on institutional consolidation, CAS has established national comprehensive research bases, including: (1) The Academy of Mathematics and Systems Science (on the basis of Institute of Mathematics, Institute of Systems Science, Institute of Applied Mathematics, and Institute of Computational Mathematics & Scientific/Engineering Computing); (2) National Astronomical Observation and Research Center (on the basis of Beijing Astronomical Observatory and in conjunction with observatories in Shanghai, Purple Mountain, Yunan and Urumqi, and Satellite Observation Station in Changchun);

(3) Shanghai Institutes of Biological Sciences (on the basis of eight CAS institutes[6], the National Research Center for Gene and the Shanghai Research Center for Life Sciences.

In order to promote interdisciplinary studies and cooperation among superior research institutions, CAS has established a batch of research bases by merging some institutions or setting up linkage among institutions, including: (1) Shanghai Hi-tech R&D Base (formed jointly by Shanghai Institute of Technical Physics, Shanghai Institute of Metallurgy, Shanghai Institute of Organic Chemistry, Shanghai Institute of Optics and Fine Mechanics, Shanghai Institute of Ceramics); (2) Beijing research center for material science (on the basis of the new Institute of Physics, Institute of Chemistry and Institute of Physical and Chemical Technology[7]); (3) Beijing R&D center for information science and technology (on the basis of Institute of Computing Technology, Institute of Software, Institute of Electronics, Institute of Acoustics, Institute of Automation, and Research Center for Microelectronics); (4) R&D Center for Protecting Bio-resources & Bio-diversity in Southwest China (on the basis of Kunming Institute of Zoology, Kunming Institute of Botany, Chengdu Institute of Biology, and Xishuangbanna Botanical Garden[8]); (5) Research Base for Resource, Environment and Sustainable Development in Northwest China -The Cold and Arid Regions Environment and Engineering Research Institute (on the basis of the Lanzhou Institute of Glaciology and Geocryology, the Lanzhou Institute of Desert Studies, and the Lanzhou Institute of Plateau Atmospheric Physics); (6) R&D Base for High-performance Materials & Advanced Manufacturing Technology in Northeast China (on the basis of new Shenyang Institute of Automation[9] and Shenyang Institute of Metal Research[10]; (7) Research Base for Earth Science in Beijing (on the basis of Institute of Geology and Geophysics[11]); (8) Changchun Institute of Optics and Fine Mechanics and Physics (on the basis of the Changchun Institute of Optics and Fine Mechanics and the Changchun Institute of Physics.

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[6] the Shanghai Institute of Biochemistry, Shanghai Institute of Cell Biology, Shanghai Institute of Materia Medica, Shanghai Institute of Physiology, newly established Shanghai Institute of Neuroscience, which was set up on the basis of former Shanghai Institute of Brain Research, Shanghai Plant Physiology, Shanghai Institute of Entomology, Shanghai Institute of Biotechnology.

[7] Institute of Physical and Chemical Technology was restructured on the basis of Institute of Physics, Institute of Chemistry, Institute of Photographic Chemistry

[8] Xishuangbanna Botanical Garden was formed on the basis of former Institute of Entomology and former Xishuangbanna Botanical Garden of the Institute of Botany.

[9] Shenyang Institute of Automation was restructured on the basis of former Shenyang Institute of Automation, and Shenyang Center of Numerical Control.

[10] Shenyang Institute of Metal Research was restructured on the basis of former Shenyang Institute of Metal and Research Institute of Corrosion and Protection of Metal.

[11] Institute of Geology and Geophysics was restructured on the basis of former Institute of Geology and former Institute of Geophysics.

In order to meet the demands of development of science and technology, CAS has established some new institutions such as the Institute of Earth Environment (on the basis of former CAS Research Department of the Loess Plateau) and the Institute of Neuroscience (on the basis of former Shanghai Institute of Brain Research). Meanwhile, CAS merged its Northwest Institute of Soil and Water Conservation into Northwest University of Forestry.

Following the transformation of 242 State-owned Independent Research Institutes, CAS has also transformed its institutes exclusively engaged in technological development into self-supporting enterprises. By the end of 2001, thirteen CAS affiliated institutions have already completed this institutional transition, including: the Chengdu Institute of Computer Application, the Chengdu Institute of Organic Chemistry, the Guangzhou Institute of Electronic Technology, the Guangzhou Institute of Chemistry, the Shenyang Institute of Computing technology, the Beijing Research Center of Software, and five Research Centers for Scientific Instruments in Beijing, Shenyang, Chengdu, Xinxiang and Nanjing.

In July 2001, CAS decided to shift the focus of KIP implementation onto research projects designed to meet the country's strategic needs and work to strengthen the overall planning to facilitate the development of CAS and its organizational restructuring. For this purpose CAS has implemented the Strategic Action Plan for Scientific and Technological Innovations (SAPI) since the fall of 2001, which includes three action plan, namely: the Action Plan for the Strategic Readjustment to the Pattern for the Distribution of Scientific Research and Technological Development Projects, the Action Plan for the Building of Research Forces and the Development of Education, and the Action Plan for Renovating the Managerial System of State Research Institutions.

The main objectives of the SAPI are (1) to form, based on the country's strategic needs and the actual scientific and technological development in frontier areas, a new pattern for distribution of scientific research and technological development, which meets the requirements of the third phase of national development, and is expected to remain relatively stable for at least the next two decades; (2) to make innovative changes to the managerial system and operational mechanisms with regard to a selected number of important research orientations and to organize outstanding task forces to pursue world first-class research results, and to enhance the cooperation among government, industries, universities and other institutions so as to make greater contribution to basic research and even national macro decision-making; (3) to establish public infrastructure for S&T innovation so as to promote technology transfer and industrialization of research results; to strengthen scientific communication and widespread so as to enhance scientific making of the public and to foster innovation -oriented culture; (4) to strengthen strategic consultancy so as to provide important supports to national macro decision-making; to enhance the strategic analysis and planning capability at the academy level and the capability of system integration, organization and management, with a view to establishing an organization and command system, a system for coordinating management of resources and a system for assessing innovations. These systems should commensurate to S&T innovative capability of CAS.

The Impact of Reform in CAS

The reform in CAS has profound impact on the technological innovation in China. After three years reform CAS becomes much more powerful and effective than before.

First of all, the reform has rationalized the structure of human resources by introducing a new mechanism featuring public invitation, and dynamic renewal. The "big rice bowl" has been broken, which implies that all staffs should be ready to accept a higher or lower position based on their competitiveness. In this way, CAS successfully realizes a smooth transition between two generations. Besides, CAS adopts a tripartite distributive system with special emphasis on the personal performance with a view to encouraging scientists to do their best.

Secondly, the reform has consolidated research forces in CAS and strengthened the capability of original innovation in scientific research, the technological innovation capability in strategic hi-tech areas, and the capability of integrating key technologies in China.

Thirdly, the reform has improved the competitiveness of CAS, which reflects in gaining financial supports in the form of research projects from various foundation or national Science & Technology Programs, in the rapid increase of high quality papers (SCI, EI), in various international cooperative projects with France, Germany, the US, Russia and Japan, and reflects in the rapid increase of amount of graduates. Over 20,000 graduates are registered in CAS, which will become important human resources for technological innovation in China.

Finally, the reform has improved the operation condition and promoted the industrialization of R&D results in CAS. S&T enterprises affiliated to CAS got 41.5 billion yuan (US$ 5 billion) in sales and 3.7 billion yuan (US$ 4.5 million) in Pre-tax profits in 2001, about 15% and 6% higher than previous year respectively.

CAS has renewed its development guideline for the next decade as following: Catering to the national strategic demands and aiming at the world science frontiers, efforts will be made to promote original innovation in scientific research and the innovation and integration of key technologies, so as to scale the heights of world science & technology, make fundamental, strategic and forward-looking contributions to China's economic reconstruction, national security and sustainable development.[12]

The guideline embodies new connotation with regard to the strategic position, innovative targets and priorities of CAS. For instance, (1) to give top priority to the national strategic needs and link such needs to research in the frontier areas of the world science in an organic manner; (2) to enhance original innovation and scaling the peak of world science; (3) to emphasize the innovation and integration of key technologies so as to meet the challenges arising in the era of knowledge-based economy; (4) to strengthen research efforts in resources, environment and ecology so as to make great contributions to the decision-makings concerning national security and strategy for sustainable development; (5) to turn KIP results into productive forces, to incubate and develop high-tech industries, so as to contribute directly to economic reconstruction, to ensure a rapid, sustained growth of national economy.

IV. General Conclusions and Discussions

The transformation of state-owned R&D institutions into enterprises and the reform of the Chinese Academy have profound impact on restructuring national innovation system in general, and on building indigenous technological innovation capability in particular. The transformation of the 242 R&D institutions is an important breakthrough of national reform of Science & Technology System, which has very important demonstration effect for transforming other scientific institutions affiliated to other ministries (including state-owned social commonweal research institutions).

The transformation strengthens the linkage between R&D and production, and to some extent the technological innovation capability of enterprises. More and more R&D personnel join in industrial sectors after the transformation. Enterprises are gradually becoming the principal innovator, and investor in R&D. The transformation is propitious to exploiting the creativity of researchers, and to building up indigenous technological innovation capability. The market pull (economic return) and the competition pressure (survival) are original power of sustaining innovation.

The Transformation has changed the research model of the R&D institutions from government-oriented or following up foreign research organization to market-oriented. It

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[12] Lu Yongxiang: “Pushing ahead with the Knowledge Innovation Program by clarifying the new guideline for running the Academy”, a speech on January 22 at the 2002 annual working conference of the Chinese Academy of Sciences in Beijing.

also provides many opportunities for the combination of technology and capitals, which could enable transformed R&D institutions to enlarge their market share.

However, the transformation has some negative impact on technological innovation capability in China. I think that the transformation of government sector instead of R&D institutes is the key to integrating S&T and economy, and to promoting economic development. In practice, lots of problems can be solved by government only, not by R&D institutions. For example, the mobility of science and technology talents is still the most important factor affecting the transformation. The barriers to the mobility of science and technology talents can be moved only by government.

The model of the transformation is too simple, and neglects the diversity of institutes in nature and the variety of social economic demands. Most transformed institutions still need to be transformed into modern corporations or companies with mixed ownership so as to overcome the problems such as low efficiency that state-owned enterprises usually have. Some institutions provide public goods for industrial sectors, not for specific enterprises. They can not obtain enough economic returns from their research in the market to support themselves. Therefore, the transformation of these kinds of institutions may impair the technological innovation capability of some industrial sectors in China.

CAS has made great achievements in systematic reform, namely authorizing new R&D institutes, transferring some institutes to university or local government, and transforming 13 institutes into companies. By employing oversea talents, reforming operation mechanism and setting up evaluation system of performance, CAS has dramatically strengthened its original innovation capability in scientific research, in strategic hi-tech development areas, and the capability of integrating key technologies in China.

INTERNATIONAL EMULATION OF BAYH-DOLE: RASH OR RATIONAL?*

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Introduction

During the past decade, many nations have considered or enacted policies to reform their university systems so that they can better contribute to technical progress in industry and economic growth. The debates leading to such changes typically have pointed to the growth of university-industry interaction in the United States over the past 25 years or so as evidence that the American system "works," and many of the proposed changes explicitly attempt to emulate the U.S. model of university-industry technology transfer.

Specifically, many countries have adopted or are considering adoption of legislation similar to the Bayh-Dole Act of 1980, which created a uniform federal patent policy allowing universities to retain title to patents resulting from publicly funded research, and encouraged the creation of technology licensing offices at universities. Thus a recent report by the Organization of Economic Cooperation and Development (OECD) notes "[I]n nearly all OECD countries there has been a marked trend towards transferring ownership of publicly funded research from the state (government) to the (public or private) agent performing the research. The underlying rationale for such change is that it increases the social rate of return on public investment in research" (OECD 2002, 48).

Motivating these changes is the premise that Bayh-Dole enhanced social returns from university research in the United States. This belief typically is based on observations that since its passage, there has been a dramatic increase of patenting and licensing by universities in the United States, growth of university-industry interaction, and growth of "science-based" industries like biotechnology and information /communication technologies. Elsewhere, my colleagues and I have suggested that the links between the latter two trends and Bayh-Dole are tenuous: these developments were well underway in the United States before Bayh-Dole, and are largely attributable to unique structural characteristics of the American innovation system, rather than to government patent policy (Mowery et al. 2001, Mowery and Sampat 2001b).

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* Parts of this paper draw upon joint research with David Mowery and Richard Nelson. However, I alone am responsible for any errors or omissions.

In this paper, I argue that if other countries want their universities to be as economically productive as U.S. universities appear to be, Bayh-Dole type policies are likely not the answer, for several (related) reasons. First, in most industries, other channels of university-industry knowledge and technology transfer are more important. Second, the theory underlying Bayh-Dole--that intellectual property rights are needed to facilitate the development and commercialization of publicly funded university inventions--lacks evidentiary foundation. Contrary to the prevailing view that the Bayh-Dole act was a resounding success in the United States, I argue that its net social welfare effects are unclear. As such, I conclude that the widespread trend towards emulation of Bayh-Dole type policies is misguided.

The remainder of the paper is organized as follows. Section 2 provides an overview of the economic roles of universities, and the channels through which universities contribute to technical progress in industry and economic growth. Section 3 discusses the university patent practices and policies in the United States in the pre-Bayh-Dole era, to provide a baseline for comparison. Section 4 discusses the logic of Bayh-Dole. Section 5 surveys the existing data on the effects of Bayh-Dole. Section 6 concludes.

The Economic Importance of Research Universities: Channels of Technology and Knowledge Transfer

Over the past century, American research universities have been extremely important economic institutions. In a range of industries, from agriculture to aircraft to computers to pharmaceuticals, university research and teaching activities have been extremely important for industrial progress.[1] Most economic historians agree that the rise of American technological and economic leadership in the postwar era was based in large part on the strength of the American university system.

The economically important "outputs" of university research have varied over time and across industries. The literature suggests that universities' economic contributions come in a variety of forms. For example[2]:

- Universities create economically useful scientific and technological **information**, which helps increase the efficiency of applied R&D in industry, by guiding research towards more fruitful departures.[3]
- They develop **equipment and instrumentation**, which is used by firms in their production processes or their research.[4]

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[1] See Rosenberg and Nelson (1994) and Rosenberg (2001) for case studies of university-industry interaction in particular industries.

[2] This list draws from Rosenberg (1999), Cohen et al. (1998), and other sources.

[3] David, Mowery, and Steinmueller (1992) and Nelson (1982) discuss the economic importance of the "informational" outputs of university research.

- Universities provide **skills** or **human capital** to students and faculty members, as well as help create networks of scientific and technological capabilities.
- Universities create **prototypes** for new products and processes.[5]

The outputs of university research is useful not only to industry, but also feed into future academic research. Academic research is a cumulative process that builds upon itself: recall Sir Issac Newton's famous aphorism, "if I have seen further, it is by standing on the shoulders of giants."

The relative importance of the different channels through which these outputs diffuse to (or alternatively, "are transferred to") industry also has varied over industry and time. The channels include, *inter alia*, labor markets (hiring students and faculty), consulting relationships between university faculty and firms, publications, presentations at conferences, informal communications with industrial researchers, formation of firms by faculty members, and licensure of patents by universities.

To telegraph one of my conclusions, the diversity of outputs of university research, and the diversity of channels of university-industry knowledge and technology transfer, are extremely important for policymakers (in the United States and elsewhere) to keep in mind. Patents and licenses are only part of a much broader picture.

Moreover, they are not the most important part. According to the results of a recent survey of firms in the U.S. manufacturing sector (Cohen, Nelson, and Walsh (2002)) firms report that in most industries, the primary channels through which they learn from university research are publications, conferences, and informal information exchange. Patents and licenses ranked near the bottom of the list.[6] A recent study by Agrawal and Henderson (2002), focused on two major academic units at the Massachusetts Institute of Technology (MIT), provides corroborating evidence. Faculty members report that a very small fraction of the knowledge transfer from their laboratories to industry (7%) occurs via patenting. Other channels—Agrawal and Henderson focus on publications--are more important.

It is interesting that the most important channels of university-industry knowledge transfer--publications, conferences, and informal information exchange--are those associated with what the sociologist of science Robert Merton has termed the norms of "open science" (Merton, 1973), which create powerful incentives for academics to

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[4] See Rosenberg's (1994) discussion of universities as a source of scientific instrumentation.

[5] See Rosenberg (1999).

[6] There is, however, considerable inter-industry variance. Patents and licenses are considerably more important channels in pharmaceuticals than in other industries. However even in pharmaceuticals, the other channels historically have been extremely important (Gambardella 1998).

publish, to present at conferences, and to share information with (academic and non-academic) colleagues (Dasgupta and David, 1994).

University Patenting Before Bayh-Dole[7]

Indeed, throughout much of the twentieth century, universities were reluctant to become directly involved in patenting and licensing activities precisely because of fears that such involvement might compromise, or might be seen as compromising, their commitments to open science and their institutional missions to advance and disseminate knowledge. Consequently, many universities avoided patenting and licensing activities altogether, and those that did get involved typically out-sourced their patent management operations to third party operations like the Research Corporation, or set up affiliated but legally separate research foundations to administer their patents.

As discussed in more detail in Mowery and Sampat (2002a), the Research Corporation originated from the research of Berkeley chemist Frederick Gardner Cottrell, to administer his patents on the electrostatic precipitator, a pollution control device. Cottrell intended to license his patents and use the proceeds to support scientific research. Implementation of this plan, however, required the development of an organization to manage the licenses. Cottrell first considered using the University of California as a licensing manager, but rejected this possibility because of concern about the effects of licensing on the culture of scientific research at the University. He later recalled:

> A danger was involved, especially should the experiment prove highly profitable to the university and lead to a general emulation of the plan. University trustees are continually seeking for funds and in direct proportion to the success of our experiment its repetition might be expected elsewhere . . . the danger this suggested was the possibility of growing commercialism and competition between institutions and an accompanying tendency for secrecy in scientific work. (Cottrell, 1932, p. 222).

Instead, in 1912 he founded a non-profit third party technology transfer agent, the Research Corporation, to administer the precipitation patents. When he founded the Research Corporation, Cottrell also thought that it might also serve a broader purpose, namely to license patents developed by:

> the ever growing number of men in academic positions who evolve useful and patentable inventions from time to

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[7] This section draws liberally from Mowery and Sampat (2001a, b) and Sampat and Nelson (2002).

> time in connection with their regular work and without looking personally for any financial reward would gladly see these further developed for the public good, but are disinclined either to undertake such developments themselves or to place the control in the hands of any private interests (Cottrell, 1912, p. 865).[8]

This vision was fulfilled in 1937, when the Massachusetts Institute of Technology (MIT) signed the first "invention administration agreement" with Research Corporation. Under the terms of the agreement, MIT would disclose to Research Corporation inventions that it deemed potentially patentable. Research Corporation agreed "to use its best efforts to secure patents on inventions so assigned to it and to bring these inventions into use and derive a reasonable income therefrom" and further to "use its best efforts to protect these said inventions from misuse and to take such steps against infringers as [it] may deem for the best interest of the parties hereto, but with the general policy of avoiding litigation wherever practicable." All services were provided at the expense of Research Corporation. Any license income net of expenses were to be divided according to a formula by which MIT split net royalties with Research Corporation on a 60/40 basis. Research Corporation was to use its portion of the earnings to support it grants activities. Over the post-war era, and especially after World War II, universities continued to sign similar invention administration agreements (IAAs) with Research Corporation. This is illustrated in Figure 1, which shows the proportion of Carnegie research universities[9] with such agreements, from 1940-1980.

While most major universities contracted with the Research Corporation before 1980, some, especially state schools, took another approach, setting up legally separate but legally affiliated research foundations to manage patents. The first and most prominent of these was WARF, the Wisconsin Alumni Research Foundation, founded by members of the University of Wisconsin in 1924. Steenbock demonstrated a method of increasing the vitamin D content of food and drugs via the process of irradiation. Steenbock, despite the

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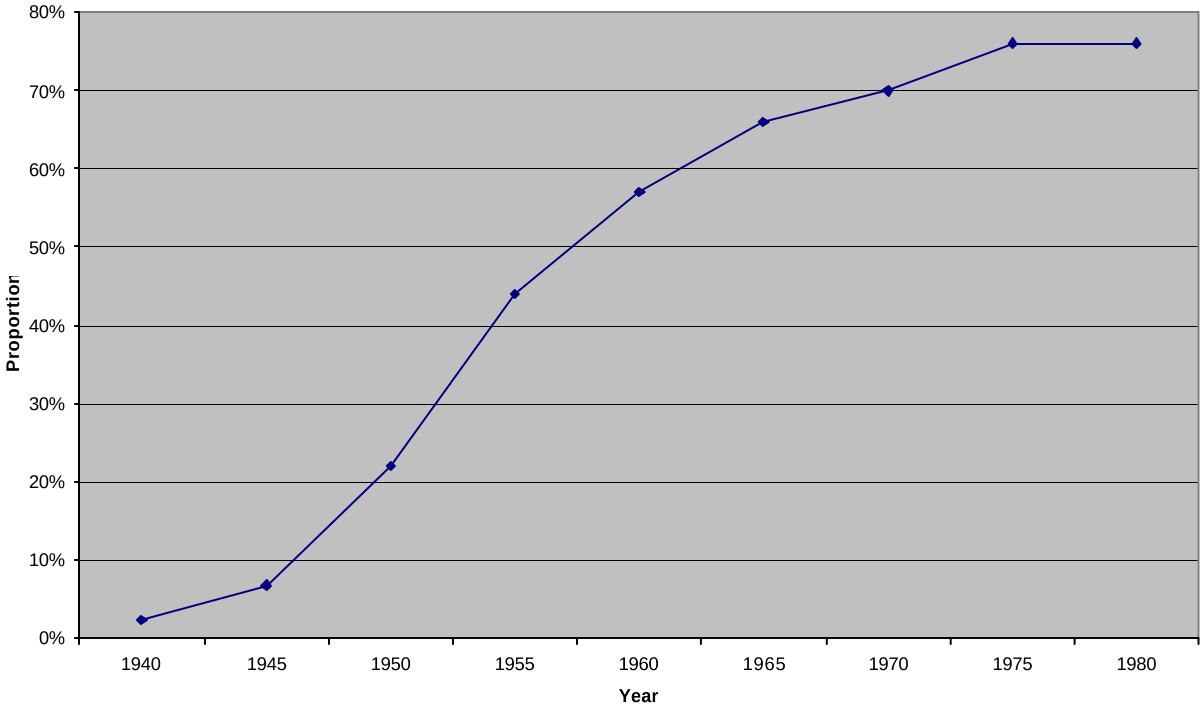
[8] In a 1911 speech before the American Chemical Society, Cottrell argued that without an entity charged with advertising, licensing, and developing academic inventions, such inventions might well fail to find any commercial applications: "a certain amount of intellectual by-products are going to waste at present in our colleges and technical laboratories all over the country. There is a great deal of work that is being developed to a practical or semi-practical standpoint that dies right there because the men . . . do not want to dip into the business side of technology and go out into practical fields and the work has not come to the point of economic usefulness that is desired" (quoted in Cameron, 1952, p. 166).

[9] In its 1973 report, the Carnegie Commission on Higher Education classified the nation's 173 doctorate granting institutions as Research Universities and Doctoral Universities. Institutions that awarded at least 50 doctorates in 1969-1970 and were among the 50 leading recipients of federal financial support in at least two of the three years 1968-1969, 1969-1970, 1970-1971 were classified as "Research University I" (RU1). Institutions that awarded at least 50 doctorates in 1969-1970 and ranked in between 50th and 100th in federal financial support in two of the three years were classified as "Research University 2" (RU2). I treat the union of the RU1s and RU2s as "Carnegie Research Universities".

criticism of many in the medical community and his colleagues at the University, wished to patent his findings. In particular, he argued that in this case patenting was necessary for quality control, i.e. to prevent the unsuccessful or even harmful exploitation of the invention by unqualified individuals or firms. He believed that incompetent exploitation of the process, which might discredit the research results and possibly the university, could be avoided by patenting the process (Apple 1996).[10,11]

Figure I: Proportion of Carnegie Research Universities with IAAs with Research Corporation: 1940-1980



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[10] Apple (1989) also notes that another more or less unstated reason that Steenbock wanted to patent the invention was to prevent margarine producers from acquiring the process, thus protecting the region's dairy interests.

[11] Blumenthal et al. (1996) conjecture that Steenbock was also motivated by the experiences of his colleague Dr. Stephan Babcock. Babcock had developed a method for determining the butterfat content of milk, and, as was then standard practice, did not file for patent protection on the invention. However, lack of patent protection limited the degree to which Babcock could prevent low-quality producers from flooding the market with "Babcock testers", eventually discrediting the method altogether. See also Apple (1996).

Once the decision to acquire the patent had been made, the question how to administer it remained. Steenbock offered to assign the patent to Wisconsin for management. However, the University was not convinced that creation of an administrative organ to handle patents was worth the necessary political and financial risk (Apple 1996). Thus a different solution was developed. Steenbock convinced several alumni to create the Wisconsin Alumni Research Foundation (WARF), a university affiliated but legally separate foundation that would accept assignment of patents from University faculty, would license these patents, and would return part of the proceeds to the inventor and the University. According to Apple (1996) the idea was that "[w]ith this structure, business matters would not concern or distract the university from its educational mandate; yet academe could reap the rewards from a well-managed patent whose royalties would pay for other scientific work" (42). Over the course of the twentieth century, a number of other institutions established similar foundations.

Via contracting out to the Research Corporation or establishment of WARF like organizations, universities hoped to insulate themselves from the business side of patent activities. While most major universities employed one of these two options in the pre-Bayh-Dole era, there was considerable variance in their formal patent policies, i.e.. faculty disclosure policies and sharing rules. (See Mowery and Sampat 2001b for specifics.) In the postwar era, many universities had "hands off" policies, refusing to take out patents as institutions but allowing faculty members to patent and retain title if they desired. Thus before 1980, Columbia University's policy left patenting up to the inventor and administration up to Research Corporation, stating that "it is not deemed within the sphere of the University's scholarly objectives" to hold patents. Others required faculty members to report inventions to university administration, and still others required faculty disclosure only in cases of sponsored research. Notably, several major universities (including some with "hands off" policies) explicitly forbade the patenting biomedical research, evidently based on the belief that restricting the dissemination of health-related inventions was undesirable. At Harvard, Chicago, Yale, and Johns Hopkins and Columbia, and Chicago, these prohibitions were not dropped until the 1970s.

In the 1970s, university patent policies and procedures began to change under the weight of several forces, described in detail in Mowery et al. (1999), Mowery and Sampat (2001a, 2001b), and Sampat and Nelson (2002). The most important source of these changes was the emergence of commercial applications resulting from the growth of "use oriented" basic research (Stokes, 1997) in fields like molecular biology. This was occurring at the same time as federal and other sources of funds for university research were declining, leading some universities to become increasingly interested in patenting as a source of income. In addition, by the mid-1970s many universities had become frustrated with the Research Corporation's failure to return license revenues under Invention

Administration Agreements (Mowery and Sampat, 2001a). This led many institutions to reconsider their patent policies and procedures, and to get more directly involved in patenting and licensing. Thus by the mid-1970s, Research Corporation's *Annual Report* noted that most major institutions were considering setting up internal technology transfer offices (Mowery and Sampat, 2001a).

In light of the historical reluctance of universities to become directly involved in patenting and licensing activities, these changes were fairly dramatic. Entry by universities into patenting and licensing activities, which began in the 1970s, was magnified and accelerated by the Bayh-Dole act of 1980.

Government Patent Policy and the Bayh-Dole Act

Before discussing these changes in government patent policy, it is worth noting that from an economic perspective, allowing for patents on publicly funded research is--at least at first glance--peculiar. As is well known, knowledge (or information) has several peculiar characteristics. First, it is non-rival, i.e. more than one actor can use a particular piece of knowledge at once, and use by one does not preclude use by another. A second characteristic, related to the first, is that the costs of transmitting knowledge to other users are low, relative to the costs of creating the knowledge in the first place. Third, once created, it is often difficult to exclude others from using a particular bit of knowledge, i.e. knowledge "spills over" to others. Because of these characteristics, economists argue that decentralized markets will typically under-invest in creation of knowledge, i.e. there is a "market failure" in research and development.

As Paul David (1993) has pointed out, governments historically have responded to this tendency for the market to under-invest in research in one of three ways (1) patronage, or government funding of research (2) procurement, or government contracting for the creation of new knowledge, and (3) property, or giving private producers of information a temporary monopoly on its use.

The patent system is the most important "property" policy. Patents give inventors the right the exclude others for making, using, or selling an invention for a limited period of time, currently 20 years in the United States. By effectively allowing inventors a monopoly on a technology, patents create inefficiencies, including the standard deadweight losses from non-competitive pricing. But, the patent system is based on the belief that the dynamic gains created by stimulating invention outweigh the static losses.[12]

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[12] Mazzoleni and Nelson (1998) offer a thoughtful survey and discussion of the benefits and costs of patent protection.

Given this classic justification for the patent system, it would seem rather strange for the government to *both* pay for research via taxpayer funds ("patronage"), and then *also* allow for the university performers to patent it ("property"). Based on the logic presented above, once the government has funded the research it would be foolish to tolerate the welfare losses resulting from patenting, and more sensible to disseminate the research outputs widely.

The framers of the Bayh-Dole act recognized this. However, they argued, a significant number of potential inventions resulting from federally funded university research were sitting "on the shelf" because, absent intellectual property rights, firms lacked incentives to develop them. That is, they asserted that the difficulties that university researchers faced in patenting their research outputs, and in licensing their patents to firms on an exclusive basis, blunted firms' incentives to develop and commercialize these inventions.

The focal examples of such inventions were embryonic pharmaceuticals, i.e. prototypes for drugs that needed considerable testing and development before they were commercially useful. Proponents argued (largely based on anecdotal evidence) that if a university researcher had an idea for a drug, no firm would be willing to do the R&D needed to bring the drug to market absent clear and exclusive rights to that drug. And to create clear and exclusive rights, the university had to hold title to the prototype and license it exclusively.

To support the proposition that granting universities title to federally funded inventions would increase social returns from federal investments in academic research, proponents of Bayh-Dole appealed primarily to statistical evidence from the Harbridge House Study of 1968 that higher rates of commercialization result when performers of research, rather than government funding agencies, hold title to patents resulting from federally funded research. Rebecca Eisenberg (1996) has persuasively argued that this inference was faulty and based on a "selection bias." Moreover, rates of commercialization are an incomplete measure of social benefits, as the public can benefit from the information embodied in government held patents even if these patents do not feed directly into commercial products. Equally importantly, the Harbridge House study dealt primarily with patents resulting from government funded research performed by *firms*, and the numbers cited above say nothing about rates of commercialization of *university* patents held by the government versus those held by the universities themselves.

Thus, the logic underlying Bayh-Dole was based on little direct evidence about the virtues of allowing universities to retain title to patents resulting from publicly funded research. There was also no discussion during the hearings about the potentially negative effects that encouraging university involvement in patenting and licensing might have on the culture of academe, or on other channels through which economic and social benefits from university research are realized.[13]

Despite this lack of evidence on the benefits (and costs) of facilitating university patenting of publicly funded research, Bayh-Dole passed in 1980, and became effective in 1981. Before Bayh-Dole, if universities wished to retain title to patents resulting from federally funded research, they had to negotiate an Institutional Patent Arrangements (IPA) with individual funding agencies (IPAs gave blanket permission to universities with "approved technology transfer capability" to retain title to agency funded inventions) or petition for title on an invention by invention basis. Bayh-Dole replaced the web of IPAs and petitions with a uniform across agencies, allowing universities to retain title to patents resulting from publicly funded research and to license them on an exclusive or non-exclusive basis.

Strictly speaking, Bayh-Dole did not legalize anything that was previously illegal. But it did reduce the costs and bureaucratic hurdles universities faced in patenting and the results of publicly funded research, and in licensing these patents exclusively.[14] More importantly, it gave strong Congressional endorsement to the position that direct involvement in patenting and licensing, activities universities had traditionally avoided, was appropriate and indeed enhanced "technology transfer" and social benefits from university research.

The Growth of University Patenting and Licensing in the United States

In the wake of Bayh-Dole, universities increasingly became directly involved in patenting and licensing, setting up internal technology transfer offices to manage licensure of university patents. Figure 2 shows the distribution of years of "entry" by universities into patenting and licensing, defined as the year in which the universities first devoted .5 FTE employees to "technology transfer activities" (AUTM, 1998). Consistent with the discussion above few universities were involved in patenting and licensing early in the century. Entry began during the 1970s, but accelerated after Bayh-Dole.

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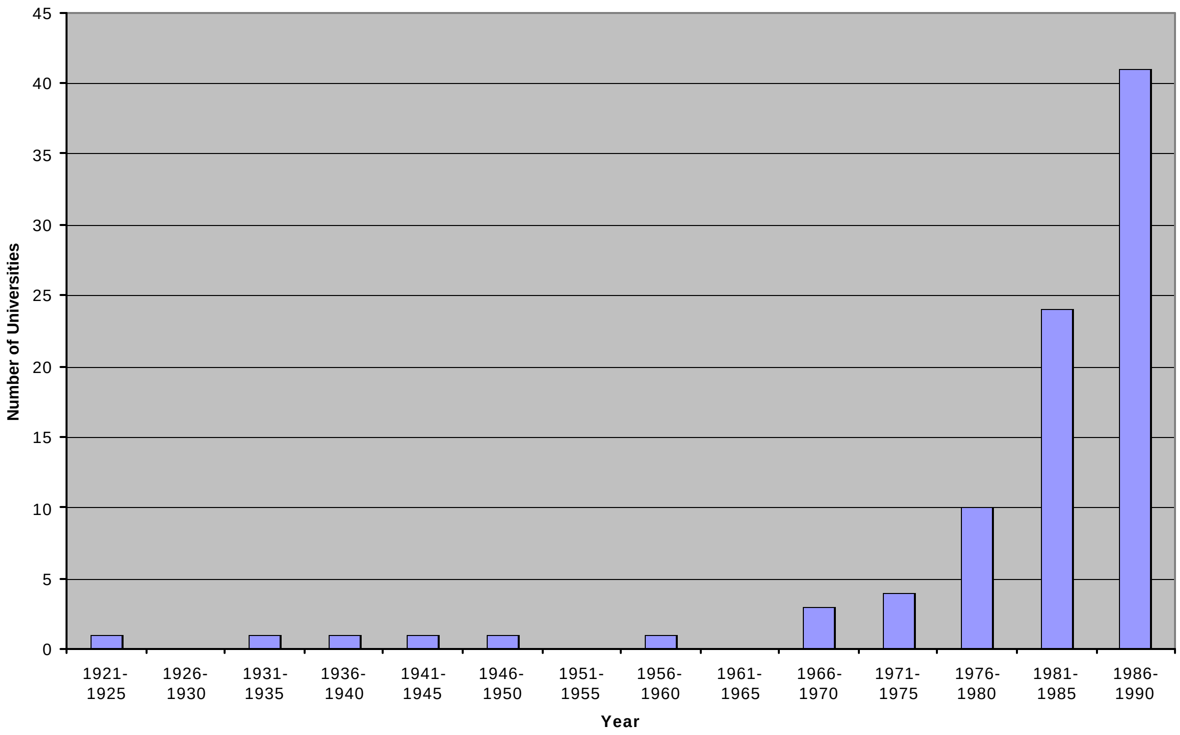
[13] A contemporary account noted that Bayh-Dole "leaves unanswered fundamental questions about patents in general and patents on university campuses in particular" even though "[p]atents run into some hallowed academic traditions, especially the publication of research results" *Bioscience* 29(5), page 284.

[14] In the pre-Bayh-Dole era, universities without IPAs had to request permission for licensing exclusively on an invention by invention basis. Those with IPAs ere required to consider non-exclusive licensing first. Bayh-Dole included no such provision, and as such made licensing inventions exclusively easier.

Figure 2: Year of "Entry" into Technology Transfer Activities



University patenting exhibits a similar trend. Figure 3 shows the total number patents issued to Carnegie research universities over the 1925-1995 period.[15] Here again, growth began during the 1970s, but accelarated after 1980.

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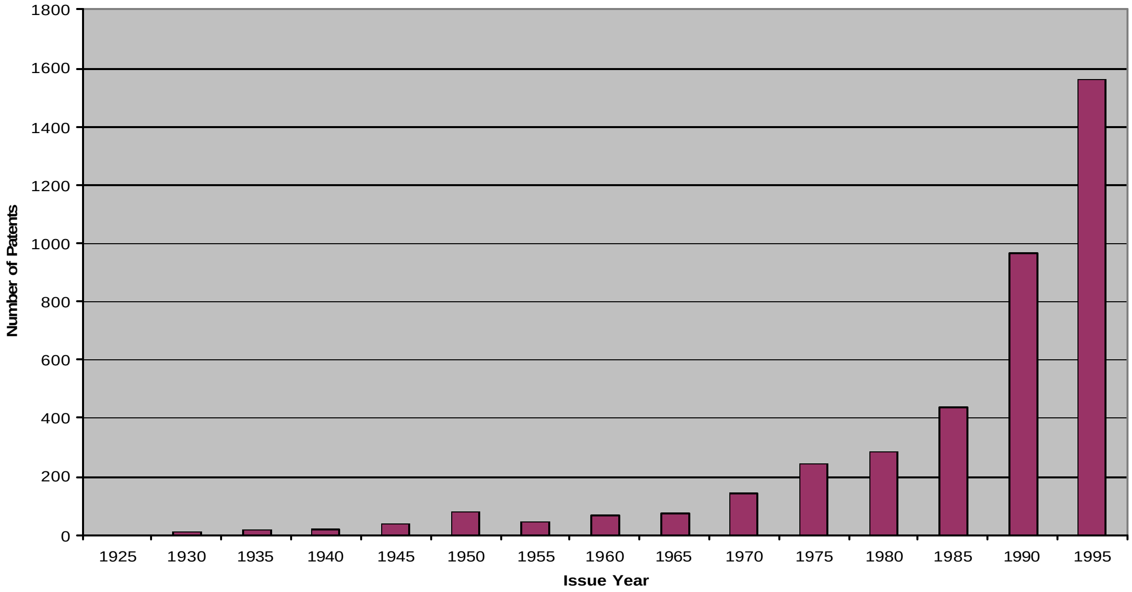
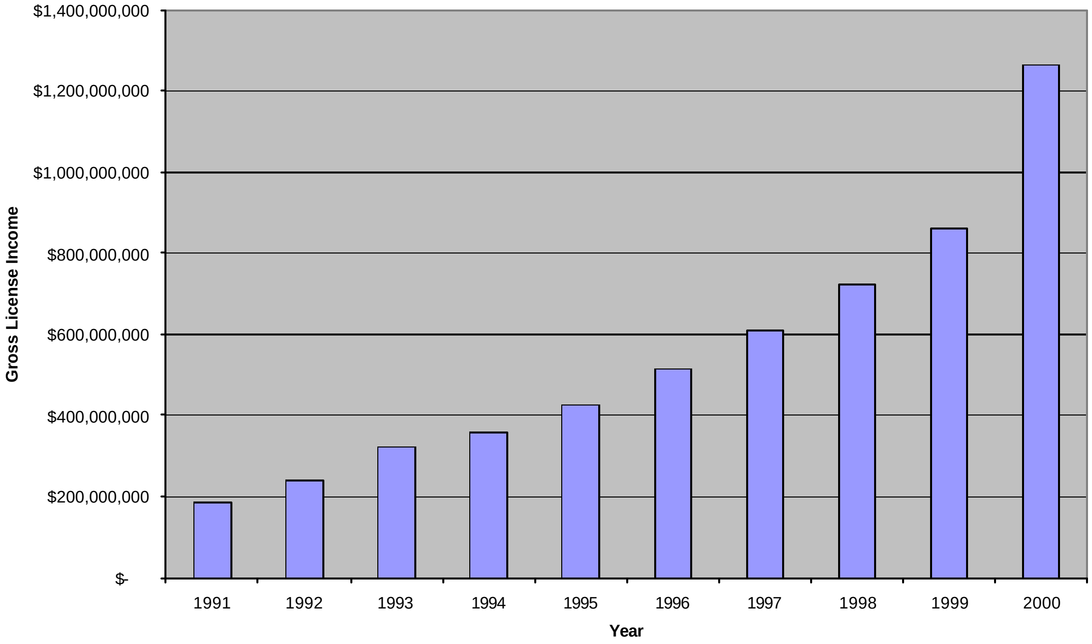
[15] These counts do not include Research Corporation patents.

Figure 3: Patents Issued to Research Universities, By Year



Time series on license revenues are more difficult to obtain, as they were not systematically collected until the early 1990s. In 1991, according to a survey by the Association of University Technology Managers (AUTM), universities earned nearly $200 million in license revenues, and this figure has increased nearly seven-fold since that time, as seen in Figure 4:

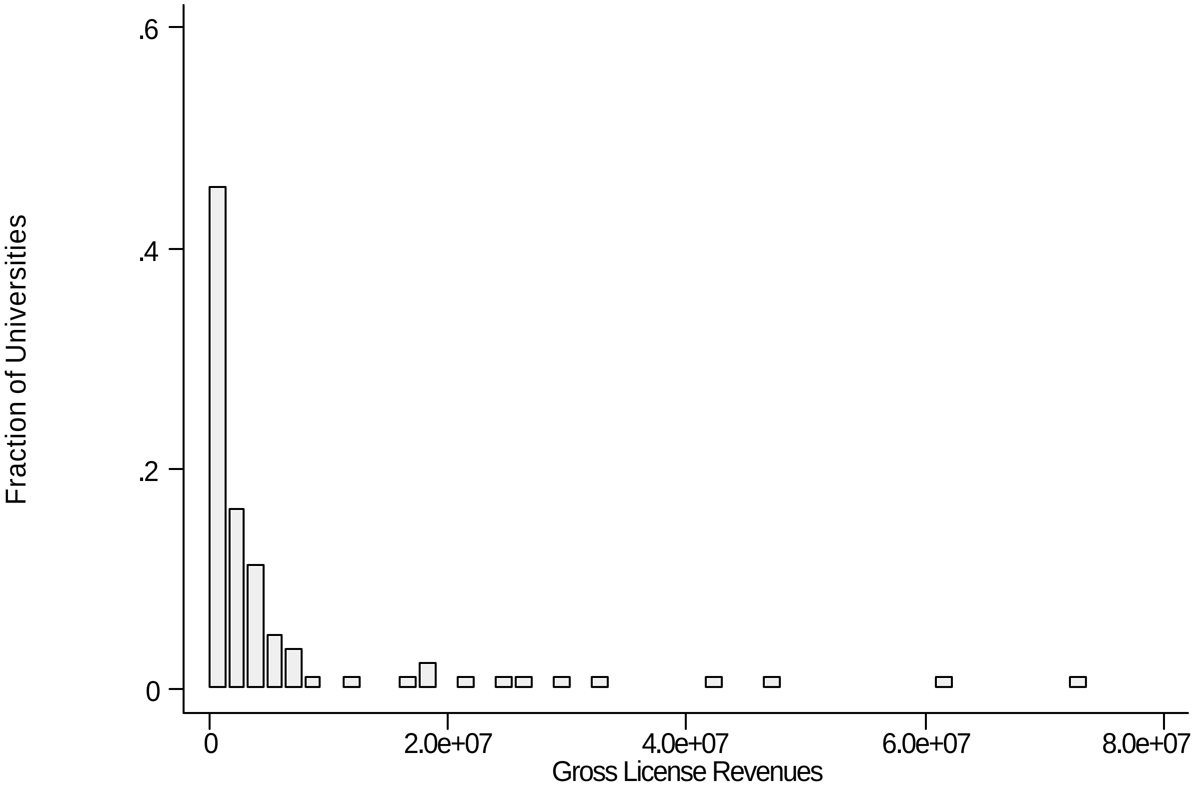
Figure 4: Gross University Licensing Income, 1991-2000
(Source: AUTM 2002)



These trends in license revenues are at least part of the motivation for emulation of Bayh-Dole in other nations. Yet they should be put in perspective. Overall, license revenues by universities generate less than 5% of all research funds at AUTM universities (AUTM 2002). Note also that this figure was calculated before subtracting the inventors' share of royalty income (typically 30-50%) and before subtracting costs of patent and license management, which can be significant.[16]

In addition, a handful of universities account for the lion's share of licensing revenues. Figure 5 shows the distribution of licensing revenues in 1998 across the Carnegie research universities. Note that few universities are making large revenues: in fact, 10% of these universities account for over 60% of total licensing revenues. Moreover, the numbers in Figures 4 and 5 are gross revenue figures, and do not include costs of patent and license management. It is likely that after taking costs into account, the majority of American research universities are losing money on their patenting and licensing activities (cf. Trune and Goslin 1997). The lesson for American universities, as well as those in other countries, is clear: patenting and licensing are not profitable activities for most educational institutions.

Figure 5: Distribution of University License Revenues



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[16] Mowery and Sampat (2001a) show that the high costs of patent management made it difficult for the Research Corporation to generate positive net income from patenting and licensing university inventions.

Social Welfare Effects of Bayh-Dole

Of course, the primary purpose of the Bayh-Dole act was not to make universities rich, but rather to promote "technology transfer." And a number of observers in the United States and abroad have looked to the patenting and licensing trends displayed above (or similar figures) and pronounced Bayh-Dole a resounding success.[17] Implicit in this interpretation is the assumption that the commercialization and development underlying these trends would not have occurred absent Bayh-Dole, or more generally absent university patenting and licensing.

This assumption is bound to be valid in some cases, but certainly not in all. The importance of patents and licensing for development and commercialization of university inventions was not well understood during the Bayh-Dole hearings, and is not well understood today. Universities can patent any inventions developed by their faculty members, and certainly do not limit their patenting to cases where commercialization would go forward even absent patenting and licensing.[18] For example, the Cohen-Boyer recombinant DNA technique was being used by industry even before the University of California and Stanford began to licensure; patenting (and licensing widely) allowed the universities to generate income, but did not facilitate technology transfer. In a recent oral history, Neils Reimers, the manager of the Cohen-Boyer licensing program, made this point explicitly, noting that

> [W]hether we licensed it or not, commercialization of recombinant DNA was going forward. As I mentioned, a nonexclusive licensing program, at its heart, is really a tax ... [b]ut it's always nice to say "technology transfer" (Reimers, 1998).

Another invention that fits this bill is Richard Axel's co-transformation process, patented and licensed by Columbia University. In this case, firms were using the technology shortly after it was described in the scientific literature, and before a patent was granted. The university compelled firms to license the invention by threatening to sue the firms if they continued to use the technology without a license.

In these two cases, technology transfer happened in spite of, not because of, university patenting and licensing activities. These are just two cases, but two important

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[17] See, for example, the recent assessment of Howard Bremer, available online at http://www.cogr.edu/Bremer.htm.

[18] According to a recent survey of 76 major university technology transfer offices, licensing incomeis the most important criterion by which technology transfer offices measure their own success (Thursby, Jensen, and Thursby 2001).

ones: together they account for close to 15% of cumulative royalty revenues earned by *all* research universities in the post-Bayh-Dole era. Here, the university revenues are "taxes" on industry (to use Reimers' language) and ultimately consumers, rather than indicators of the extent of technology transfer.

In cases such as these, where universities are patenting inventions that would have been utilized or developed even absent intellectual property rights, society suffers the standard losses from non-competitive pricing. Further, restrictive access to university inventions may result in too few sources of further experimentation and development, in a context when multiple, rivalrous development efforts may be more socially desirable (see Merges and Nelson, 1990). The share of these cases and the extent of these costs are unknown: because they involve counterfactuals they are difficult to identify and measure. But a proper evaluation of the welfare effects of Bayh-Dole would have to take these costs into account.

Such an evaluation would require additional empirical evidence on a number of other fronts, as well. As discussed in Section 2 of this paper, universities contribute to technical change in industry and economic growth through a number of channels. An extremely important issue that we know little about is whether and how universities' increased patenting and licensing activities are affecting these other channels. Given that publication, conferences, and informal information exchange are important channels of university-industry knowledge and technology transfer--and universities historically have avoided direct involvement in patenting and licensing precisely because of fears that these activities might adversely affect the operation of these channels associated with "open science"--any assessment of Bayh-Dole that fails to mention these potential effects is necessarily incomplete.

A related concern is that universities are increasingly patenting inputs into academic research, rather than technologies, and that restrictive licensing of "research tools" may be creating friction in the process of academic research itself (Eisenberg and Heller 1998). The line between "technologies" and "research tools" is extremely blurry—especially in fields like biotechnology--and systematic evidence about the costs introduced by such patenting is not available. Nonetheless, this is another potential dimension that needs to be considered before one can make a judgment about whether the net effect of Bayh-Dole, and increased university patenting and licensing more generally, has been positive or negative.

In short, an evaluation of the effects of Bayh-Dole based simply on trends in university patenting and licensing is incomplete, since such an assessment overstates the benefits and ignores the costs. It may well be that the net effect was positive in the

United States, but this conclusion cannot be made based on the evidence presently available. Nor can the conclusion that the net effect has been negative. At this point, we simply do not know.

Conclusions

In light of this lack of evidence, I conclude that international emulation of the Bayh-Dole act is more "rash" than "rational." There is simply no evidence for the claim that allowing and encouraging universities to patent and license publicly funded inventions increases social returns from university research.

American universities historically have been extremely important economic institutions, and the American system of university-industry interaction surely deserves study by other nations attempting to stimulate economic growth or foster the growth of indigenous science based industries. However, the success of the American system is due to a range of policies and institutions, including *inter alia* significant public funding for use-oriented basic research, a tradition of institutional autonomy and inter-institutional competition, and high levels of mobility between academe and industry. Policymakers in other nations would be better served focusing on these aspects of the American university system, and on fostering more conventional channels of university-industry knowledge and technology transfer, rather than trying to emulate Bayh-Dole.

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University Affiliated Enterprises in China: Evolution and Assessment[1]

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I. Introduction

In recent years, the rise of knowledge economy has led to the recognition of the essential role technological innovation has played in economic development. The concept of innovation system has been adopted to explain mechanisms of knowledge creation and dissemination at national, regional or sectoral levels (Freeman, 1987; Lundvall, 1992, Nelson, 1993; Saxenian, 1994; Edquist, 1997; Breschi & Malerba, 1997). A primary focus of these studies is on the role of different players of innovative activities and the interaction of these players. In particular, many have focused on the new roles of universities in the division of labor in national innovation systems and their linkages with the industry in fulfilling these roles.

While the innovation system approach presents a useful framework for one to examine the role of universities from an institutional perspective, most of these studies, however, are based on the experience of industrialized countries. Hardly anyone has looked into these issues in the setting of a developing country, such as China. The Chinese experience is interesting not only because China is a large developing country, but also because China is moving towards a market economy with a centralized innovation system in transition. the academic-market linkage in China offers a unique case to study the evolving institutional relationships between academia and industry since China's innovation system has experienced a dramatic change over the last 15 years. The evolution of the university-market linkages in China has been greatly influenced and conditioned by such change.

In addition, as the trend of globalization of S&T continues, academic communities in developing countries will increasingly become important partners in a global innovation system. Therefore, the academia-market interface in these countries matters not only because such experience can shed new lights on the ongoing debate,

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but because the evolution of such relationship will also have an impact on the interlinked global innovation system.

In this paper, I will focus on the evolution of the university-market linkages in China, with a special attention to university-affiliated enterprises. In the next section, I will give a brief account of theoretical arguments surrounding the role of the university in a national innovation system and the linkages between university and the market. In section three, I will examine the way university-affiliated enterprises are created, their industrial distribution, their contribution to the development of indigenous high-tech industries, and the problems and controversies surround them. In section four, I will discuss the pull and push factors that shaped the current university market linkages. I will focus on the evolution and reform of China's national innovation system, and the lack of fundamental reform in China's higher education system as the general background against which Chinese universities interact with the market in various forms. Finally, implications of the current university market linkages for the overall Chinese innovation system will be explored.

II. Theoretical issues

The proper role of the university in a national innovation system, or more broadly, in a knowledge economy has increasingly become controversial in recent years. While there is a consensus on the role of the university in disseminating knowledge through teaching activities, there are certain disagreements in its role in generating knowledge[3], and even less agreement on its linkage to the industry and the commercial market.

Theoretically, the work of Nelson (1959) and Arrow (1962), Merton (1973), Dasgupta and David (1994) has laid the foundation for the division of labor between industrial research and academic research. Nelson and Arrow examined the economics of knowledge production through investment in industrial research by profit-maximizing firms. The investment decision in R&D is guided by the return to this investment. Nelson and Arrow argue that while the generation of scientific knowledge through R&D is costly, transferring this knowledge is relatively easy. Once produced, the knowledge will not diminish or degrade as the result of usage by different firms. From societal point of view, therefore, the widest possible diffusion of this knowledge is optimal. However, because the practical use of scientific knowledge is limited and the price of transfer is low, the firm that has discovered this knowledge can hardly recover its investment in R&D. As a result, the social returns to R&D investment far exceed the private return faced by the individual firm, which would

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[3] The disagreement mainly comes from the division of labor between public research institutes and universities. In the U.S. academic research is mainly carried out in universities, particularly research universities. Whereas in Europe, national laboratories, such as those operated by French National Committee for Scientific Research (CNRS), play the central role in academic research (Noll, 1998).

lead to under investment in basic research. The identification of this important market failure has provided theoretical justification for the public support of basic research most of which is carried out in either universities or government labs, while firms are left to engage in industrial research typically carried out in their own labs.

In a similar vein, Merton argued for the separation of industrial and academic research out of the concern for efficiency. In his view, academic research has its own motivations that are centered on the efficient creation of knowledge and advance of scientific frontiers. The quest to discover and publish early creates a productive competition which leads to quick dissemination of information (Merton, 1973, Florida and Cohen, 1998). Dasgupta and David (1994) presented an economic argument which also favors keeping academic and industrial research separate. They argue that industrial research focuses on profit and intellectual property while academic research is a quest for fundamental discovery. Intermingling the two would distort resource allocation and hence, have negative social welfare implications.

In reality, however, the picture is more complicated. In both the U.S. and Japan, the world number one and number two R&D spenders, university-industry links have "an old and honorable history." In the U.S., industrial funding for university research was close to 8% through most of the 1950s, dipped to as low as 2.5% in the late 1960s, and has been on a steady rise through 1980s and 1990s, reaching 7.1% in 1997. While such support to university research takes many forms fom contracted research to individual consulting, university-industry cooperative research centers are seen as an effective means to promote the linkages between industry and university, and has been strongly supported by National Science Foundation (Hane, 1999). In Japan, university-industry links after World War II became largely informal and consultative, based on networks of individuals rather than of institutions ((Kodama and Branscomb, 1999).

In this configuration of the innovation system, the scientific knowledge generated from academic research is assumed to be exploited by industrial firms at almost no cost. In recent years, however, the argument that knowledge transfer from academia to industry is a cost-free process has been challenged. In particular, studies by Rosenberg (1982), Mowery (1983), Pavitt (1987), and Cohen and Levinthal (1990) indicate that transferring and utilizing scientific knowledge is itself a costly and knowledge intensive process. This process, which has been ignored by neoclassical economic analysis of R&D, is heavily influenced by the division of labors among different institutions in an innovation system and the networks and coordinating mechanisms in the system, as well as by the internal cooperation and coordination among R&D, marketing, and production functions in a firm.

One way to characterize the institutional relationships among university, industry, and the government is the so-called 'triple helix' model. In this model, the university is a key element of the innovation system both as human capital provider and seed-bed of new firms in the emerging knowledge economy (Etzkowitz, 1999). The three institutional domains, public, private, and academic, that formerly operated at arms length in laissez faire societies, are increasingly interwoven with a spiral pattern of linkages emerging at various stages of the innovation processes.

The key issues in this debate lie in the proper role of academia in an innovation system and to what degree this role is dependent on the specific historical and institutional environment of the innovation system. The contrast between the neat theoretical division of labor among universities and other institutions of a national innovation system and muddy reality of interwoven relationships among these players is no more apparent than the university-market linkages in China, where universities have become major players in the market. The next section will examine a special form of such linkage in China: university affiliated enterprises.

III. University affiliated enterprises: a special case of university-market linkage

While there is no formal definition, university-affiliated enterprises refer to those enterprises that are still in one way or another controlled by the universities they are affiliated with. Legitimacy of this control derives from the fact that many these enterprises were created by funds from universities and many universities are still the largest shareholders in these companies. In some other cases, enterprises willingly submit their management control to universities so that they can generate intangible benefits for themselves. In this section, I will briefly review the development of university-affiliated enterprises, examine the current status of these enterprises, their contribution to the development of indigenous high-tech industries, and the problems and controversies surround them.

3.1. A brief historical review of the development of university affiliated enterprises

University affiliated enterprises are not new things for Chinese universities. Many Chinese universities, particularly those engineering and science-based universities, have had university-affiliated factories since 1950s, which are mainly used for students to get short-term internship or apprenticeship in a real production environment. Also, under the "work unit system," (a self-sufficient organizational system for enterprises, universities, and other social institutions in China after the founding of the People's Republic of China. For detailed discussion on the system, see Lu (1990).), many Chinese universities had its own service providers such as print shops, publishers, guest-houses, and so on. What was new was the new market environment, the new roles these enterprises are playing (or expected to play) and the complex relationships they have developed with their parent universities.

The development of university-affiliated enterprises can be divided into three stages. The first stage is from early 1980s to 1990. During this period of time, China just began to implement its reform and open door policy. In 1985, the Central government issued a decree on structural reform in educational system "The resolution of the Central Committee of the Communist Party of China on the structural reform of the education system" (CCCCP, 1985) that also encouraged the educational institutions to engage in the economic and social development of the general society. Faced with the commercial opportunities in the society and their internal financial need, the traditional university affiliated service providers began to open up to the general society while many new services were also created. Most of their operations were focused on technology transfer, technology development, technology consulting, and technology service (MOST, 1999).

University-affiliated enterprises during this stage were run under three models. The first one was university affiliated factories or print shops. The second model was to bring university technologies to create joint commercial entities with enterprises outside universities. The third model was technology development companies created by universities and departments. By 1989, sales of university-affiliated enterprises reached 470 million yuan (Li, 2001).

However, many of university-affiliated enterprises in the early stage were short term profit oriented and poorly managed, which generated some controversies on whether it was appropriate for Chinese universities to run enterprises. In order to address this issue, the then State Commission of Education, State Science and Technology Commission and the Investigation Office of the General Office of the Party formed a joint investigation team in November 1990. The team visited over 30 universities in Beijing, Shanghai, Nanjing, and other cities to look into the issue. The team submitted a report that endorsed the development of university-affiliated enterprises.

The second stage of university-affiliated enterprises was from 1991 to 2000. In 1991, China's State Council issued its endorsement of university-affiliated enterprises on a document submitted by Commissions on Education and Science and Technology to provide guidelines for administering university-affiliated enterprises. Since then, particularly after Deng Xiaoping's southern tour in 1992, university-affiliated enterprises have been developing at an accelerated speed. In 1992, sales of university-affiliated enterprises jumped to 2.9 billion yuan from 1.76 billion yuan in 1991. By 1999, this number reached 37.9 billion yuan.

The third stage started from the year 2000 when new controversies began to surface again over the appropriateness of universities getting involved in running enterprises. There were also concerns about the potential financial risks that universities were exposed to by the university-affiliated enterprises that were traded in the stock markets. Further, increasingly more university-affiliated enterprises felt the need to change the governance structure so that they can operate like real commercial enterprises. Recently, the government has begun to encourage universities and the affiliated enterprises to "de-link." Clearly, university affiliated enterprises in China are now at a new cross road.

3.2. Current status of university-affiliated enterprises in China

In the year of 2000, there were 5451 enterprises affiliated with regular Chinese universities. Table 1 presents an overall picture of the development of university-affiliated enterprises. As can be seen that over the past several years, university-affiliated enterprises have maintained their growth momentum in terms of sales, profit, and tax paid, except in 1998.

Table 1. Growth of University-Affiliated Enterprises (billion yuan)

Year	Sales	Profit	Tax paid	Income to Universities
1997	29.55	2.72	1.23	1.58
1998	31.56(6.8)	2.59(-5.6)	1.35(9.7)	1.50(-5.1)
1999	37.90(20.1)	3.05(18.0)	1.66(18.6)	1.59(6.0)
2000	48.46(27.9)	4.56(49.5)	2.54(53.3)	

(Source: S&T Development Center, Ministry of Education. Figures in () indicate growth rate.)

Of the 5451 enterprises, 2097 were classified as S&T enterprises. While the number of university-affiliated S&T enterprises was less than half of the total, these enterprises accounted for over three quarters of the total sales in 2000 (see Table 2). Further, in the year 1999, close to 90 percent of the income to universities were generated by these S&T enterprises. Also the growth rate of sales, profits, tax paid for S&T enterprises were all higher than other enterprises.

Table 2. Growth of University-Affiliated S&T Enterprises (billion yuan)

Year	Sales	Profit	Tax paid	University income
1997	18.49	1.82	0.69	0.68
1998	21.50 (16.3)	1.77(-2.7)	0.83(21.0)	0.66(-3.8)
1999	26.73(24.3)	2.16(21.8)	1.10(31.9)	1.39((111.6)
2000	36.81(37.7)	3.54(64.3)	1.88(71.4)	

(Source: S&T Development Center, Ministry of Education, Figures in () indicate growth rate.)

Table 3. General Statistics of University-Affiliated Enterprises by Enterprise Characteristics in 2000 (billion yuan)

Enterprise Characteristics		Number of enterprises	Total Income（billion yuan）	Total Profit（billion yuan）	Total Tax Paid（billion yuan）
Business Orientation	Production	1995	28.61	2.66	1.54
	Trade & related service	849	4.35	0.24	0.16
	Others	2607	15.50	1.66	0.85
Ownership Structure	Owned by university	4793	32.18	2.51	1.61
	Joint ventures with domestic partners	556	14.37	1.81	0.83
	Joint ventures with foreign partners	102	1.90	0.24	0.11
Level of Management Control	University	4217	45.53	4.38	2.41
	School, Department	1234	2.93	0.18	0.13

(Source: S&T Development Center, Ministry of Education)

Table 3 shows the general statistics of university-affiliated enterprises in 2000 based on different characteristics of these enterprises. In terms of business orientation, about half were engaged in production and trade, with the rest in other businesses such as running a guest house.. It is clear that enterprises in production generated more income, profit and tax on a per capita basis. In terms of ownership structure, 88 percent of the enterprises were owned by universities, with some domestic and international joint ventures. It is interesting to note that at the enterprise level, joint ventures with domestic partners performed much better than both university single ownership and international joint ventures. In addition, about 80 percent of the enterprises were managed at university level. These enterprises performed much better than those managed at the school or department level.

3.3. Analysis of universities with strong university-affiliated enterprises

While there are many university-affiliated enterprises in China, only a very small proportion of the enterprises are successful. The same is true from the point of view of universities. Many Chinese universities have university-affiliated enterprises, but only a small number of them have successful ones. Successful and influential university-affiliated enterprises are concentrated in a small number of selected universities. In fact, the total sales of top ten universities in terms of enterprise sales reached 26.7 billion yuan in 2000, accounting for over 55 percent of entire sales generated by university-affiliated enterprises in China. Therefore, to analyze the growth of university-affiliated enterprises, one must also examine their parent universities in order to understand the characteristics of Chinese university-affiliated enterprises.

Table 4 presents some overall features of the top 20 universities with highest enterprise sales. Taken together, sales of enterprises in this group accounted for 65 percent of total sale realized by Chinese university-affiliated enterprises. A careful examination of this group will find that universities in this group can be classified into three categories.

The first category is universities classified as "engineering type" in the old classification system by State Commission of Education. This classification system is based on the fact that in 1952, Chinese universities were restructured following the Russian approach, including comprehensive universities and specialized colleges and institutes, in engineering, medicine, language, and so on. While many of these specialized colleges and institutes have made great effort to develop a broader disciplinary base and changed their names since early 1980s, their current comparative advantages and weaknesses are still influenced by that history. In our top-20 group, there are 13 universities belong to this category. This is consistent with our previous finding that S&T enterprises are the backbone of the university-affiliated enterprises. It also indicates that the comparative advantages of parent universities, strong engineering research and talented faculty and students, are an important source of strength for the university-affiliated enterprises.

The second category is universities classified as "comprehensive type" in the old classification system. In the 1952 restructuring, engineering disciplines in these universities were taken away while basic sciences were allowed to stay. Since 1980s, these universities have also started to broaden their academic basis by developing engineering disciplines, particularly in those areas where strong basic science is needed. Four comprehensive universities in our top-20 group are in this category. They are also among the most prestigious universities in China. While there is no official ranking of universities in China, unofficial ones have begun to appear in recent year. In the column "university ranking," I adopted one of these unofficial ranking of universities which is based on a number of academic performance indicators and has become quite influential (Netbig, 2002). The four comprehensive universities in our group (based on enterprise sales) also happen to be the best comprehensive universities based on academic performance. This fact indicates that academic strengths and reputation is another important contributor to the strong growth of university-affiliated enterprises.

Table 4. Top 20 Universities with highest total sales from affiliated enterprises (in 2000)

Sales Ranking	Name	Sales (million yuan)	Old Classification	University Ranking	Location
1	Beijing Uni.	11006.71	Comprehensive	1	Beijing
2	Tsinghua Uni.	6287.89	Engineering	1	Beijing
3	Shanghai Jiaotong Uni.	1728.72	Engineering	7	Shanghai
4	Haerbin Polytechnic Uni.	1654.20	Engineering	11	Haerbin
5	Northeast Uni.	1324.84	Engineering	30	Shenyang
6	Petroleum Uni. (East China)	1239.74	Engineering	52	Beijing
7	Nankai Uni.	1200.06	Comprehensive	8	Tianjin
8	Fudan Uni.	1157.02	Comprehensive	3	Shanghai
9	Xian Jiaotong Uni.	1128.05	Engineering	6	Xian
10	Zhejiang Uni.	1120.96	Engineering	5	Hangzhou
11	Tianjin Uni.	963.25	Engineering	8	Tianjin
12	Tongji Uni.	874.70	Engineering	18	Shanghai
13	Southwest Jiaotong Uni.	408.82	Engineering	40	Chengdu
14	Jiangxi Uni. Of Chinese Medicine	376.94	Medicine		Nanchang
15	Nanjing Uni.	371.86	Comprehensive	4	Nanjing
16	Huazhong Uni. Of S&T	367.99	Engineering	14	Wuhan
17	China Civil Air Flight College	344.80	Engineering		Tianjin
18	Chongqing Uni.	329.37	Engineering	38	Chongqin
19	Shanghai Foreign Language Inst.	323.89	Language		Shanghai
20	Beijing Foreign Language Inst.	286.65	Language		Beijing

(Source: compiled by author)

The third category is universities that belong to neither “engineering type”, nor elite “comprehensive”, but rather, have their unique comparative advantages. Out of the three universities in our top-20 group, one is Jiangxi University of Chinese Medicine. The lion’s share of its enterprise sales comes from a nationally well-known pharmaceutical company for Chinese medicine, Jiangzhong Pharmaceutical. The other two universities are two best-known foreign language universities in China. Their unique market niche comes from the huge population who want to learn foreign languages, demand for which have been increasing dramatically since China’s opening up more than 20 years ago. Their sales mainly come from sales of language learning material and services.

Last but not least, all these 20 universities are located in largest cities in China, such as Beijing, Shanghai, Tianjin, Chongqing, and major provincial capitals, such as Xian, Nanjing, Chengdu, and so on.

3.4. University-affiliated enterprises on the stock markets

A unique feature of Chinese university-affiliated enterprises is that some of them have been publicly traded on the stock market since late 1990s. By 1999, there are 16 such companies listed on the stock market, up to the mid-2000, this number increased to 25. Some of these companies went on public through their own IPOs (specify), while others went on public through purchasing “the shells” of existing public companies. The “university block” has become a significant player in China’s stock market. It has also been a source of controversies. The following analysis is based on data provided by the 16 publicly traded companies at the end of 1999.

As can be seen from Table 5, most the listed companies have increased the publicly traded shares dramatically, indicating their capabilities in raising funds through the stock market. Except two companies mainly engaged in retailing industry, all others were in high-tech industry, particularly in IT industry. For seven out of sixteen companies listed, IT industry is their principal area of operations. Other areas include medicine, agricultural products, retailing, and generic S&T activities. In four of the 16 companies, universities are the majority shareholders, indicating the absolute control of the companies by these universities. While universities do not have majority shares for the other 12 companies, most universities were still the largest shareholders, giving them enough power to control the direction of the companies.

While raising capital from the stock market has been hailed as a new step for the development of university-affiliated enterprises, there are also controversies surrounding the publicly traded companies with university connection. For example, some people think that these companies have used names of the universities improperly to attract potential investors. This might be helpful to the company in the short term, but could be damaging for the university in the long run.

Table 5. Characteristics of Publicly Traded Companies with University Connections (1999)

Name of the company	IPO /or initial purchase (10,000 shares)	Line of industry	1999 (10,000 shares)	% controlled by university/university share holding companies
Fuhua Shiye	4339.09	Multi—High tech	20267	Fudan Uni. (32.74)
Jiaoda Nanyang	6600	IT-high tech R&D	14473.07	Shanghai Jiaotong Uni. (43.70)
Tongji S&T	5008.57	Engineering projects	15269.47	Tongji Uni. (42.20)
Gongda Gaoxin	10000	IT-high tech R&D	32409.1	Haerbin Polytechnic Uni. (34.99)
Dongda Alpine	4500	IT-Software and System Integration	21650.13	Northeast Uni. (32.00)
China Hi-Tech	10000	IT-high tech R&D	17460	Joint ownership of 52 Uni. (17.68)
Tsinghua Tongfang	11070	IT products & services	25933.9	Tsinghua Uni. (53.18)
Tianda Tiancai		IT products and software	10275.46	Tianjin Uni. (49.10)
Huashen Group	6600	Medicine	7920	Chengdu Uni. Of Chinese Medicine(36.36)
Yunda Hi-tech	8100	Agricultural S&T products & service	14100	Yunnan Uni. (22.89)
Zheda Haina	6000	Electronics-equip. and parts	9000	Zhejiang Uni. (62.44)
Tsinghua Ziguang	8880	IT products & services	12880	Tsinghua Uni. (62.11)
Funder Tech		Light Ind.-office equipment&utensils	18662.4	Beijing Uni. (5.08)
Qingniao Tianqiao	4743.55	Retail & high-tech services	11905.75	Beijing Uni. (23.03)
Nankai Gede	13340	Retail & high-tech services	16556.52	Nankai Uni. (50.98)
Mingtian Keji	9868	Chemical ind.	22652.6	Beijing Uni. (63.44)

(compiled by the author based on data provided by S&T Development Center, Ministry of Education)

IV. Jumping into the sea --the pull and push factors in shaping university-market linkages in China

The current university-market linkages in China are shaped in large degree by various pull and push forces, which are the result of the S&T system reform started in 1985, the change in macro-economic environment, and the slow reform in higher education system.

4.1. The general background—China's innovation system and S&T system reform

Unlike some other developing countries that lack indigenous R&D capability, China managed to build a national innovation system with significant scale over the past 50 years. However, as China's economic reform progressed, it was increasingly clear that China's innovation system could not meet the demand from a more market oriented economic system.

China's innovation system after 1949 was very much influenced by the Russian model. It was a mission-oriented system with strong centralized administration. Table 1 provides a general profile of the structure of China's innovation system in 1987, when China just began its reform on innovation system. The division of labor among the three types of R&D institutions was as follows: public research institutes (PRIs) were responsible for conducting the majority of China's R&D activities; universities were responsible for S&T training with limited involvement in R&D; and enterprise R&D units were responsible for production, prototyping, and other downstream innovation activities.

Table 6. A profile of China's innovation system in 1987

Types of R&D Institutions	**Number of R&D Institutions**	**R&D Personnel**	**R&D expenditures (in million yuan)**
Public Research Institutes (PRIs)	5222	385,857 (47.2%)	10,683 (60.7%)
Universities	934	178,292 (21.8%)	700 (4.0%)
Enterprise R&D Units	5021	252,781 (31.0%)	6,214 (35.3%)
Total	11,177	816,930 (100%)	17,597 (100%)

Source: (Xue, 1997)

The major deficiency of this system was the separation of R&D activities from production processes and the market. Most PRIs, including research institutes under Chinese Academy of Sciences, were funded by an annual budget from either the central or local government, conducted research projects guided by five-year national plans or other central or local plans. Industrial managers rarely had any input in such plans. Scientific and technological knowledge was perceived as free public good, leaving little incentive for researchers in PRIs and universities to transfer their results to commercial applications. Thus, transfer of R&D results from PRIs and universities to industry was, if not under the organization of the planning body, left mostly to serendipity.

Because of the problems discussed previously, reform on China's innovation system was unavoidable. Reform started soon after the economic reform began in the agricultural sector. In 1985, Chinese Government published a landmark resolution on the Structural Reform of the Science and Technology System in China (CCCPC, 1985). The essence of this reform was to make China's research organizations directly serve the need of national economic development. The reform focused on making important changes in funding system, establishing technology markets, introducing new approaches to the management of research organizations and so on, to create regulatory conditions and incentives to make R&D organizations responsive to market needs, or in Chinese expression, to push them "jumping into the sea."

After more than a decade's reform, China's innovation system has made important changes (see table 7). As a result, government appropriation decreased as a source of income for PRIs by an average of 5% each year from 1986 to 1993. By 1993, only 28% of the income of PRIs came from direct government appropriation, compared to 64% in 1986. PRIs were able to generate close to 60% of their income from non-governmental sources, half of which came from the provision of technical services by PRIs to industrial enterprises (SSTC, 1994, 1995). Similar changes also happened to universities. Government funding constitutes less than half of many universities' operating budget. They too have to diversify their sources of financing, for example, by raising the tuition, providing technical services to industrial enterprises, or running their own enterprises. Table 10 shows the characteristics of R&D activities performed by various R&D organizations. As can be seen that both PRIs and universities have put their R&D emphasis on applied research and development work, reflecting the trend discussed above.

Table 7. A profile of China's innovation system in 1999

Types of R&D Institutions	**Number of R&D Institutions**	**R&D Personnel (in 1000 person)**	**R&D expenditures (in billion yuan)**
Public Research Institutes (PRIs)	4728	234(28.5%)	26.12 (38.5%)
Universities	3124	176 (21.8%)	6.35 (9.3%)
Enterprise R&D Units	11237	351 (31.0%)	33.67 (49.6%)
Other	3134	61 (7.4 %)	1.75 (2.6%)
Total	22223	822 (100%)	67.89 (100%)

Table 8. China’s R&D expenditure by types of activity and institutions in 1997
(in 100 million yuan)

	Basic research		**Applied research**		**Development**		**Total**	
	Amt.	%	Amt.	%	Amt.	%	Amt.	%
Research Institutes	15.04	7.28	69.59	33.7	122.05	59.0	206.68	100
Universities	9.72	16.7	31.92	54.9	16.50	28.4	58.14	100
Enterprises	2.05	3.6	25.48	12.3	179.26	84.1	206.79	100
Others	0.64	6.2	3.98	38.5	5.71	55.3	10.33	100
Total	27.45	5.7	130.97	27.2	323.52	67.1	481.94	100

(Source: created by author based on (MOST, 1998))

Despite the tremendous progress China has made over the last 20 years, the national innovation system in China still suffers from a number of deficiencies that hamper the system from achieving its full potentials.

4.2. The pull factor—Opportunities due to the lack of industrial R&D capability

One of the major problems with China’s innovation system is the weak industrial R&D capability. In general, the crucial player in the innovation process is business enterprises that translate R&D results into profitable products or processes. Without a strong and effective industrial R&D capability, efforts by universities, research institutes, or other organizations often become futile. The current status of industrial R&D capability in China can be illustrated by results of a 1996 innovation survey of large and medium sized industrial firms in 6 provinces and cities conducted by the Ministry of Science and Technology.

The provinces and cities covered include Beijing, Shanghai, Guangdong, Jiangsu, Liaoning and Haerbin. They are either China’s economic powerhouse (such as Beijing, Shanghai, Guangdong, Jiangsu) or China’s traditional industrial bases (such as Liaoning and Haerbin). In addition, the average firm size ranges from 21622 employees (for Special Large Class in a Chinese classification system) to 796 (for Medium II). Small firms are not included. Even for this somewhat selected group, the situation is not encouraging. It was found that, while 73 percent of the firms surveyed had engaged in some forms of innovative activities, they spent only 3.7 percent of the total sales for these activities, of which, more than half (54.7 percent) was spent on purchasing equipment. Only 0.5 percent of total sales were spent on R&D (MOST, 1999).

One reason for this situation is that many large and medium sized state-owned enterprises (SOEs) are undergoing governance and managerial reforms. Such reform has become the top priority of China's economic reform. However, such a challenging task could not be expected to complete overnight. Under such circumstances, many of them simply do not have the financial resources needed for R&D investment. Therefore, without some fundamental changes in the external financial environment and internal management in these SOEs, there is little hope that they can be active in R&D activities. While in recent years non-state owned industrial enterprises are playing increasingly more important roles in China's economy, most are still relatively small compared to large and medium sized SOEs. Their R&D activities are limited at present. However, in the long run, non-state sector will become one of the most important forces in R&D commercialization.

The lack of in-house R&D capability in most Chinese industrial enterprises means that they could not rely on themselves for solving more complex technical problems in their production. They are also incapable of acquiring external knowledge in tacit and more dynamic forms. Thus, these enterprises need technical services from research institutes and universities. _This is partly why technology contracts have become major sources of funding for university research.

The weak industrial R&D capabilities also meant that many potentially useful research work in universities, particularly those conducted in engineering schools and departments would have a hard time to be commercialized by firms outside universities. At the same time, the rapid technological change in many high-tech and traditional industries have also created many technical and economic opportunities for these research works. Some faculty members with entrepreneurial spirit naturally see the opportunities and began to "jump into the sea". However, few of them were willing to give up their jobs in the universities. Most of them wanted to have a safe cushion in case their venture failed. For a long period of time, many universities indeed provided such safe cushion. To understand why would universities be willing to do so, we need to examine the push factor of the equation.

4.3. Push factor—Slow reform in higher education system and government policy orientation

Since mid-1980s, there have been a number of related factors that have helped to push universities to establish closer linkages with the market. These factors include slow reform in higher education system and government policy orientation.

The major difficulties in China's higher education system lie in its heritage from a planned economy where central government played key roles in determining everything from faculty salary to the number of students to be admitted in a specialty in a particular university. The autonomy of Chinese universities is much less than state-owned enterprises in other industries. At the same time, the environment where universities operate has dramatically changed to one that is very market oriented. The mismatch between the centralized system and its market-oriented environment has created many tensions and pressures that have prevented China's higher education system from adapting itself to meet the new challenges brought about by the new changes.

One constant challenge is funding shortage. Table 9 shows the income structure of a nationally well-known university in selected years in 1990s. As can be seen that government appropriation, often tied up closely with the number of undergraduate admissions, was only about one third of the total budget and was declining slowly throughout the 1990s. The largest sources of income came from research, including those from government research projects, industrial collaborations, and etc. The contribution of university-affiliated enterprises to universities comes in two ways. One is through contracted research and the other is payback to universities. The former is included in the "Research" category while the latter is included in the "Other" category. Unfortunately, detailed data on the payback of university-affiliated enterprises to universities are difficult to get.

The heavy reliance on research funding was mainly due to the slow reform in the higher education system. Reform proposals to grant universities more autonomy and to take a more market-oriented approach in financing the higher education system were debated but not implemented until very recently (Xue, 1999). While tuition and fees increased rapidly, it started from a low base and government regulations prevented them from increasing substantially. Thus, universities in China were put in a difficult position: they were not provided with enough funding to operate, nor were they provided enough autonomy to take a more market-oriented approach to finance their operation. Providing S&T service was then a very attractive and legitimate way for many universities to finance their operations.

Table 9. An Example of the Income Structure of a Well-known Chinese Univ.

	1990	**1992**	**1994**	**1996**	**1998**
Total income (Million yuan)	152.1	222.6	342.3	532.7	741.9
Gov't appropriation (%)	36	30	32	32	29
Tuition and fees (%)	2	4	8	10	11
Research (%)	48	53	49	45	41
Donations (%)	0.2	0.0	0.0	2.5	4.2
Others (%)	13	12	12	11	15

(Source: collected by author)

A further analysis of sources of research funding for universities in China from mid-1980s to late 1990s shows an interesting pattern. In 1985, when the S&T reform and educational reform started, funding from government for university S&T activities accounted for about 75% of the total. The rest mainly came from the industry. Since then, the government proportion had been declining steadily while industry proportion had been rising also steadily. By mid-1990s, industry surpassed government slightly to become the largest source of funding for university S&T activities. While there have been fluctuations since, industrial source remains to provide close to half of the funding of university S&T activities. To a certain degree, universities, particularly those with engineering background, have begun to depend on industrial research income to support the daily operations of the universities.

Government policy orientation also played an important role. Since the Central Government issued the policy documents on S&T system reform and education system reform in 1985, the government policy orientation has been consistently focused on pushing universities to offer their research service on the market, to help the economic and social development of the society. After the State Commission of Education and the State Commission of S&T issued their policy guidelines in support of university-affiliated enterprises and won the endorsement of the State Council in 1991, the two Commissions jointly with the State Commission of Structural Reform, held a national working conference to promote the development of university high-tech industry further. University high- tech industrial development has become one of the top priorities for university administrations. Local governments at various levels also see universities as engines of economic development and tried to provide various incentives and supportive policies to encourage universities to forge closer ties with local industry.

To summarize, government appropriation for Chinese universities has been far from adequate over a long period of time. Research funding from industry has become a major source of income for universities. Given that research funding from industry accounts for almost half of the total research income, universities naturally encourage its faculty to develop closer ties with industry, or even to become entrepreneurs themselves. In addition, the endorsement of the Central government and the fact that university-affiliated enterprises have become a priority of university administration have also played important roles. These factors may help to explain why university-affiliated enterprises have become so popular in China but not in other developing countries that may have similar push and pull factors.

V. Conclusion

In previous sections, we have reviewed the theoretical debates on the role of universities in applying knowledge for economic benefits of the society, and discussed the university-market linkages in China, with a particular focus on university-affiliated enterprises. Finally, we have analyzed various forces that shaped the current relations between universities and market in China. While these discussions have helped to explain why things happened, they have not been able to answer the normative questions of whether the current university-market linkage is appropriate and what should be the healthy linkages. To do so would require much more empirical evidences and careful analysis. Here, by way of conclusion, let me offer some personal observations and thoughts.

Of all the forms of university-market linkage, informal consulting, technology contracts, licensing, and university science parks have now become universal around the world. The most controversial is the university-affiliated enterprises which are, to a certain degree, unique to China. Whether one likes it or not, university-affiliated enterprises, along with those high-tech enterprises affiliated with government research institutes, have grown into a major force in China's high-tech industry. Such enterprises have made a unique contribution to the development of high-tech industry in China.

If one examines China's high-tech enterprises, two groups emerge. The first group is best represented by enterprises in Pearl River Delta in Guangdong province. Many of these enterprises were joint ventures with foreign capitals and technologies. They basically followed the traditional path of how latecomer" developing countries catch up with the developed countries. (Amsden, 1989). As Hobday (1995) describes, such path typically starts with low cost labor assembly, progressing from OEM (original equipment manufacturing), through ODM (original design manufacturing), to OBM (original brand manufacturing). It is a "bottom-up" upgrading process in which different kinds of skills are acquired sequentially according to level of their sophistication.

What makes China's high-tech industry development unique is a new path some of China's firms are following. Lu (2000) traced the development of China's computer industry and found that the leading Chinese computer companies followed a new path of technological development. All these firms started directly with certain kinds of indigenous innovation at the level of product redesign or product design. Once they secured market acceptance for their new and innovative products, they then moved on to upgrade their technological capabilities, either by moving from product redesign to product design, or by continuous product upgrading. The continuous innovations in product design reinforced market acceptance until the market was large enough to allow the exploitation of economy of scale in production. These enterprises then started to invest in building up manufacturing capabilities. Lu termed this path as the top-down model in technology learning, which may not be the most accurate term. A more appropriate description of this process is 'middle entry and upstream and downstream expansion after entry.' A major contributing factor in this approach was the close relationship between the university-affiliated enterprises and universities. These enterprises are hence in access to knowledge resources of universities and can take advantage of China's indigenous R&D capabilities accumulated over past decades.

Accelerated commercialization of R&D results from university yielded benefits for the society. One such case is the nuclear imaging device used for checking smuggling in custom developed by Tsinghua Tongfang, an enterprise affiliated with Tsinghua University. The initial research work was done by professors at the

Engineering Physics Department in late 1990s when smuggling in China was rampant. The professors saw the market potentials but did not have the resources and capabilities to bring a viable product to the market in time. They could not find an industrial partner who would be willing to carry on the research needed to bring the idea to product. It was through Tsinghua Tongfang, working closely with the Engineering Physics Department, that finally brought the product to market, which became a huge commercial success and played an important role in the fight against smuggling. One of the important institutional arrangement was that at one time, some of the key faculty members become full time employees of Tsinghua Tongfang in order to bring the tacit knowledge gained in the research stage to the manufacturing stage. Such an arrangement would be almost impossible for other companies without any linkage with the university.

While there maybe still other non-trivial benefits one can list, there are many serious problems that need to be sorted out before one can endorse university-affiliated enterprises without reservation. The first issue is related to the division of labor between different social institutions. Are there comparative advantages that are inherent to universities in carrying out its basic mission of education and research? What are the explicit and implicit social contracts in such social division of labor? Is there a change in the comparative advantages of universities in the new social and technical environment? Currently, these issues are not well thought in China. Policy orientation and institutional design are also somewhat confusing. For example, while universities are supposed to be the only social institutions responsible for higher learning, but the government does not provide enough funding to universities for such purpose. Nor are universities allowed to raise their tuitions to become self-sufficient. It is these distortions in policy that force many universities or faculty members to engage in activities that may or may not be in their best interests in the long run.

Another problem related to university-affiliated enterprises is the impact of such activities on the academic environment and its potential on university research directions. In our interviews on this issue, some complained that too much commercial activities on campus have changed the academic environment which is hurting basic research. Others consider this as an inefficient way of allocating R&D resources and have distorted directions of university research. Many faculty members and graduate students are no longer engaged in academic research. Rather, they are doing application works whose commercial values are far greater than their academic values. Further, university administrations also have to devote time and energy in running university-affiliated enterprises.

A related question is to what degree one could attribute the slow improvement in university teaching quality in China to university-affiliated enterprises. This is a complicated question to answer and there are little systematic data to support the argument one way or another. In the years prior to the reform, one of the missions of many university-affiliated enterprises was to improve teaching by providing students with better "hands on" opportunities. This mission seems to have become less important in latter years. Many people who are involved in university-affiliated enterprises have become full-time employees in the enterprises rather than professors in their original academic departments. This is particularly true since late 1990s. On the other hand, there is a general agreement that along with the reform in S&T system since 1985, Chinese academia, including public research institutes and universities, have become more commercially and application oriented. Government policies in general have supported this trend. University-affiliated enterprise is one of many outlets for faculty and researchers to release their commercial talents. Therefore, while it is somewhat unfair to blame university-affiliated enterprises for slow improvement in teaching quality, it is reasonable to say that university-affiliated enterprises have contributed to the overall trend of over-commercialization of academia.

Still, some people think that university-affiliated enterprises expose universities to undue financial risks. Of all the university affiliated enterprises, only a small percentage is making money, many are losing money and running in huge debt which generates significant financial burden for the universities.

Partly as the result of the debate started in late 1990s, many university-affiliated enterprises have begun to reform their governance structures. Many discussions have shifted from whether university should run enterprises to what should be the "exit strategy" for universities. There are two sets of problems here. First of all, for public companies where universities have controlling shares, the question is how to reduce the shares owned by universities, a problem quite similar to many state owned enterprises (SOEs) on the stock market. Theoretically, universities can use the money to build their endowment fund for their long-term development, similar to many US private universities. In reality, China's vulnerable financial market may not be able to absorb the shares owned by universities, which was why the government's attempt to reduce the government's share of many public SOEs failed in 2001.

The second problem is how to sort out the ownership structure of those university-affiliated enterprises that are not on the stock market. Universities started these companies by investing some seed money, or by providing some equipment, office space, and other non-tangible support. Managers of these companies have also contributed a great deal to the success of some of these companies with salaries below the market rate. How should one count the contribution of universities and individual managers? For those companies in bad shape, who is responsible for those debts?

In conclusion, there are historical and institutional rationales that fostered the emergence of university-affiliated enterprises over the past two decades. They have made significant contribution to the growth of China's high-tech industry. At the same time, with the continuing reform of China's national innovation system and the maturing of China's high-tech enterprises, the gap between academia and industry will become narrower. Traditional technology transfer approaches such as licensing will be more important. The advantage of university-affiliated enterprises will become less appealing. It is encouraging to see that many universities have begun to pay attention to the issue of governance structure of these companies. The policy and managerial challenge is how to help university-affiliated enterprises continue to play their role in China's high tech industry while minimize the potential damages to the academic world.

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C. Innovations in Large Enterprises and Their Supply Chains

Baosteel: from High-level Acquisition to Indigenous Innovation

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1. Great changes of China's steel industry over the past decade

1.1. A brief evolutionary history of China's steel industry

China's steel industry has undergone a rapid development with remarkable achievements in the past 10 years, which makes China undoubtedly the largest steel producer in the world, as well as the only nation that is enjoying a high-speed and continuous production increase among the major steel manufacturing countries. During the past decade, China's steel output has been increasing at an average rate of 5.86 million tonnes per annum. Economic experts forecast that China's steel production will exceed 180 million tonnes within first 10 years of the century.

Table 1-1 China's Historical Steel Production

Year	1900	1943	1949	1957	1965	1978	1985	1990
Steel output (mil tonnes)	2.6 (iron)	92.3	15.8	535	1233	3178	4679	6535
% of World output			0.1	1.83	2.66	4.42	6.50	8.48
World rank			26	9	8	5	4	4

Year	1994	1995	1996	2000	2005(e)	2010(e)
Steel output (mil tonnes)	9241	9536	10124	12850	> 15500	> 18000
% of World output	12.67	12.61	13.46	15.40	> 17	> 19
World rank	3	2	1	1	1	1

1.2. Enhanced energy utilization level

Over the past decade, China's steel output has been doubled while the overall industrial energy consumption increased only 30%, as shown in Table 1-2.

Table 1-2 Energy Consumption of China' s Steel Industry

Year	Total national energy consumption (mil. tonnes SCE)	Steel industry's energy consumption (mil. tonnes SCE)	% of national total	Comprehensive energy consumption per tonne of steel (tonne SCE per tonne steel)	Continuous casting rate (%)	Open-hearth steel rate (%)
1980	602.75	70.9	11.76	2.04	6.2	31.4
1985	766.82	77.8	10.15	1.746	10.8	26.3
1990	987.03	98.7184	10	1.611	22.66	20.1
1995	1311.76	123.9082	9.45	1.44	46.4	13.7
1996	1360.1	129.6917	9.54	1.392	53.3	12.5
1997	1381.73	126.7245	9.17	1.164	60.7	8.9
1998	1360	128.2978	9.43		68.8	4.7
1999	1220	128.6981	10.55	1.083	77.38	1.5

1.3. From 1990 to 2000, continuous casting ratio had increased 59.26% to a world average level, with cc slab output exceeding 100 million tonnes and ranking first in the world.

1.4. China is speeding up its elimination of dated process and equipment in respect of open-hearths, mini BFs, primitive coke ovens, primitive sintering machine, small converters, small EAFs and Belgian mills. More large-sized facilities are being installed.

1.5. Current satisfying rate of market demands bas been over 92%. With further implementation of technical renovation on high value-added steel grades such as cold-rolled steel, stainless steel and silicon steel, China' s steel industry will greatly enhance its market-satisfying rate and provide a powerful support to other sectors as well as the national economic development.

1.6. Steel manufacturers' technical & economic indices have been significantly improved. (As shown in Table 1-3)

Table 1-3 Changes of Technical & Economic Indices of China's Steel Industry over the past 10 years

Indicator	Unit	Year 1990	Year 2000	% Of change
Grade of BF charged materials	%	53.51	56.81	+ 3.30%
Coke ash	%	14.50	12.19	- 2.31%
Coke rate	kg/t	525	429	- 96 kg/t
Pulverized coal injection rate	kg/t	35.43	118	+ 82.57 kg/t
Continuous casting rate	%	22.66	81.92	+ 59.26%
Molten steel refining rate	%	1.28	22.5	+ 21.22%
Small shape continuous rolling rate	%	19.11	50	+ 30.89%
Sheet/strip rate	%	28.86	34.54	+ 5.68%
Comprehensive yield	%	85.14	92.82	+ 6.68%
Comprehensive energy consumption	Kg ce/t	1611	906	- 705 Kg ce/t

* Numbers of 2000 are preliminary due to the unavailability of formal data from National Bureau of Statistics of China

1.7. Thanks to the technology development and effective project implementation in the field of environmental protection, steel output is increasing rapidly while the discharge of major pollutants (except SO_2) is comparatively decreasing at the same time. Key environmental indicators have been improved to dome degree.

Table 1-4 Summary of Key Indicators on Environmental Protection

Rank	Key indicators	Year 1990	Year 1995	Year 2000	Goal of Year 2005
1	Recycling rate of water for industrial use (%)	76.07	80.96	87.04	92.00
2	Fresh water consumption per tonne of steel (m^3/t)	58.15	45.14	24.75	16.00
3	Waste water discharge per tonne of steel (m^3/t)	48.11	34.46	17.22	9.60
4	Ratio of waste water treatment (%)	93.21	96.19	98.63	100
5	Ratio of discharged waste water up to standards	77.82	82.17	88.90	100
6	Ratio of controlled waste gas treatment (%)	86.95	93.64	96.01	100
7	Ratio of controlled waste gas emission up to standards (%)	70.19	85.91	90.66	100
8	Recycling rate of ferrous dust and sludge (%)	83.25	89.97	96.42	98.00
9	Comprehensive utilization rate of BF slag (%)	79.59	84.32	86.18	90.00
10	Comprehensive utilization rate of steel slag (%)	61.04	79.36	82.14	85.00
11	Utilization rate of coke oven gas (%)	97.21	98.14	98.00	99.00
12	Utilization rate of BF gas (%)	91.27	87.98	91.73	97.00
13	Utilization rate of converter gas (%)	30.70	54.68	40.68	70.00
14	Dust-falling rate in plant (t/month·km^2)	61.03	49.36	43.86	35.00
15	Greening coverage rate in plant (%)	18.39	21.46	23.65	26.00
16	Potential greening coverage rate in plant (%)	90.85	89.16	91.00	94.00

1.8. Both the geographic production distribution and the industry concentration ratio have undergone a significant change. In 1990, there were only 15 enterprises whose steel output was more than 1 million tonnes, accounting for 60.5% of total national production. In 2000, however, the numbers had been increased to 36 manufacturers and 82.46% respectively, as shown in Table 1-5 and Table 1-6.

Table 1-5 Geographic Distribution Changes of China' s Steel Industry (%)

Year	1950	1970	1980	1990	1998	2000
North	12.72	19.96	21.51	22.69	26.10	25.82
Northeast	82.83	37.32	26.44	20.89	14.30	14.16
East	1.95	23.70	24.74	27.57	31.60	31.91
Central & South	0.90	13.57	15.05	16.64	15.80	15.75
Southwest	1.61	4.51	10.34	9.38	8.80	8.93
Northwest	0	0.94	1.91	2.82	3.40	3.43

Table 1-6 Chinese Steel Manufacturers with Output Over 1 mil. Tonnes in 2000

Types	Company	Output of 2000 (tonnes)	% Of total national
Extra-large: Over 6 million tonnes per annum (4 companies)	Baosteel (Group)	17,722,957	13.91
	Anshan	8,812,412	6.92
	Shou Gang	8,032,632	6.30
	Wuhan	6,651,656	5.22
	Total	**41,219,657**	**32.35**
Large Over 3 million tonnes per annum (7 companies)	Benxi	4,223,397	3.32
	Baotou	3,924,811	3.08
	Ma' anshan	3,922,381	3.08
	Panzihua	3,595,009	2.82
	Tangshan	3,195,492	2.51
	Handan	3,150,094	2.47
	Ji' nan	3,030,278	2.38
	Total	**25,041,462**	**19.66**

2. Baosteel and its open system of technological innovation

2.1. A brief introduction of Baosteel Co. Ltd.

2.1.1. Baosteel started its construction on December 23, 1978, with a total investment of 12 billion US dollars. The Phase I Construction was completed in September 1985, with an annual capacity of 3.2 million tonnes of steel. Phase II was completed in June 1991 and the annual capacity was 6.71 million tonnes. In December 2000, the Phase III Construction was completed and the annual capacity was increased to 11 million tonnes. Currently, Baosteel' s major products include cold-rolled & hot-rolled sheet, hot dip galvanized sheet, electro-galvanized sheet, tinplate, electrical steel, color coated sheet, wire rod and seamless pipes.

2.1.2. The quality guideline of Baosteel is "Be oriented towards customers, improvement, efficiency and value. Provide the society with world-class products and services." In December 1994, Baosteel obtained ISO9002 certification from British

Standards Institution (BSI). The ISO9001 was obtained in May 1995. ISO14001 in January 1998 and QS9000 in November 1999.

2.1.3. Baosteel's international marketing network has covered many countries around the world, from South Africa, Australia to United States and Brazil. Five domestic service centers of steel processing and distribution have been established, with two of them in Shanghai and one each in Tianjin, Hangzhou and Guangzhou. Two more centers are already under construction with one in Qingdao and the other in Chongqing.

2.1.4. A brief introduction of the steel manufacturing process.

The process is briefly described as follows:

- Sinter and coke are major materials charged into the blast furnace. Sinter is produced from fine raw ore, small coke, limestone and lots of other materials on a sintering strand while coke is produced from a mixture of coals in an oven.

- Once these materials are charged into the furnace top, they go through numerous chemical and physical reactions while descending to the bottom of the furnace. In the end, the final product, which is hot metal, is produced.

- The liquid iron then flows into refractory lined ladles known as torpedo cars due to their shape.

- Hot metal and scrap are then charged into the converter for steel making. After that, the steel is tapped into a ladle for secondary refining.

- Then molten steel is poured into a reservoir at the top of a continuous caster. It passes at a controlled rate into a water-cooled mould where the outer shell of the steel becomes solidified. At the end of the machine, slabs, blooms and billets are produced.

- The slabs, blooms or billets are then transported to the hot rolling mill for rolling into steel products. Slabs are used to roll flat products, while blooms and billets are mostly used to roll long products.

- The most common flat products at this stage are hot-rolled coil and plate. Part of them are delivered to the customers while the others go through further processing called cold-rolling.

- Typical cold-rolled products include galvanized coil & sheet and cold-rolled coil & sheet, which are finally shipped to the customer.

As one of the top 10 world's largest steel manufacturers, Baosteel follows the principle of "collaboration and division of labor" at every link of its principal business value chain, from procurement and import of raw material, equipment and technology to manufacturing and export of finished products, showing an attitude of opening up to the world. The philosophy of openness is applied to all the links in Baosteel's technology innovation chain, which include R&D, intermediate experiment and technology commercialization and exporting. Based on an open system for technological innovation and through effective utilization of social resources and its innovation practice, Baosteel is approaching its goal of becoming the most competitive steel complex in the world.

2.2. Intensified technological investment with an aim to accelerate its pace of R&D.

2.2.1. Baosteel has been strengthening its efforts on technological exploration, endeavoring to transform towards indigenous development. Baosteel's R&D investment rates are shown as follows.

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
R&D investment rate (%)	1.3	1.5	0.86	2.7	3.2	3.1	2.7	2.5	3.02	3.72	4.02

2.2.2. The company is also reinforcing the construction of its scientific research bases. By the principle of "promoting construction through projects," Baosteel plans to invest 250 million Yuan to establish more than 10 intermediate experiment bases and key labs in the fields of electromagnetic metallurgy, thin strip casting, etc.

2.3. The principle of openness and preferential policies enjoyed by Baosteel Technology Center

2.3.1. The employment of R&D personnel is mainly through acquisition, either from domestic or abroad. For those introduced researchers, a visiting expert mechanism and a "migratory bird" policy have been set up to guarantee their freedom of job mobility.

2.3.2. Management of R&D personnel is on an open basis. Baosteel Technology Center is entitled to make its own arrangement of the positions in a flexible way according to the requirements of research projects.

2.3.3. Incomes of R&D personnel are 30% higher than those of technical staff on-site.

2.3.4. Part of the R&D personnel work on a flextime basis.

2.3.5. R&D personnel have the priority to take part in varieties of training programs and technical exchange activities at home and abroad on a periodic or random basis.

2.4. Improvement of technological innovation capability through open cooperation

Baosteel has been seeking new forms of its industrial-educational-research cooperation among enterprises, colleges and research institutes at home and abroad to speed up the construction of its talent highland and improvement of its technological innovation capability.

2.4.1. Six partners, including Harbin Institute of Technology, Northeast University, Central Iron & Steel Research Institute and others, have been assessed and evaluated respectively in terms of their R&D competencies and cooperation effectiveness, with an intention to extend Baosteel's "Standard Implementation" requirements to these organizations so that the partnerships will be on a more centralized, steady and long-term basis, and the distribution of cooperation will be optimized with an improved cooperation quality.

2.4.2. By the principle of "promoting construction through projects," Technology Center of Baosteel appoints visiting researchers from the partnering colleges and institutes as well as retired Baosteel Experts to head or participate in its R&D projects. There are more than 10 Baosteel Experts are currently involved. In 1999, Baosteel Co., Ltd. alone signed 189 contracts of cooperative development projects with related domestic colleges or institutes, with an estimated value of RMB 46 million Yuan.

2.4.3. Baosteel has also co-established the Electromagnetic Process Research Center and the Vacuum Spraying Metallurgical Lab with partnering colleges and institutes, and jointly conducted a number of advanced, high-level and leading technical researches.

2.4.4. In August 2000, nationwide-oriented Iron & Steel United Foundation was co-founded by Baosteel Group Corporation and NSFC (National Natural Science Foundation of China), with its goal to fund basic technology research programs in iron and steel related fields.

2.4.5. Baosteel spared 10 million Yuan and founded its Talent Award Fund for the cultivation and promotion of its R&D talents.

2.4.6. In addition, a number of overseas training bases have been established, respectively located in New York State University (USA), College of Business and Economics at West Virginia University (USA), University of California at Berkeley (USA), University of Twente (Netherlands), University of Wales (UK), and some other universities in Canada and Germany. Training cooperation with Mitsui and Mitsubishi were also set up. So far, nearly 100 Baosteel employees have been selected and sent to the above-mentioned bases for training.

Baosteel carries out its technological innovation in a way of acquisition, absorbing, digestion and indigenous innovation. At the beginning of 21st century, Baosteel is now undergoing its transformation from a technology-assimilation oriented company to an innovation-focused one, committing itself to the innovation practice on a comprehensive, multi-leveled and wide-scoped basis. The focus of its R&D projects has been shifted from self-centered standalone applications to leading-edge technology researches that contribute to the development of global steel industry, such as thin strip casting, electromagnetic metallurgy and so on, in an effort to strengthen Baosteel's core technical capabilities.

2.5. Implementation of a fully integrated production, marketing and R&D strategy across the company to break down functional boundaries under the open philosophy of innovation

To facilitate technology innovation, boundaries among functions in Baosteel need to be eliminated so that the R&D, production and marketing processes can be effectively connected and will operate in an integrated way with the support from all related divisions. Under the teamwork spirit of "Shared Vision, Shared Responsibilities and Shared Information," joint efforts are exerted to tackle the key problems occurred at every link of the value chain. The strategy of Production-Marketing-R&D Integration is applied to the major new products. A few of key-problem-solving teams were formed with the focus on container sheet, pipeline steel and tinplate respectively. Through this approach, customer's feedbacks and market demands are clearly identified, so that the direction of new product development is more precisely targeted, existing products are upgraded, and costs are reduced at every link of the value chain with improved qualities, which finally results in accelerated transferring and commercialization of research findings, expanded market share and a solid foundation for long-term researches and critical technology development.

2.6. Close interaction of technology innovation bridging Baosteel and its customers based on direct and open research cooperation

Baosteel is strengthening its force in research of customer usage technologies, with an aim of advising customers to utilized Baosteel products in an effective way.

2.6.1. Baosteel has set up a number of technical service groups and agencies in Shanghai Volkswagen, China FAW Group and Liaohe Oil field, and is gradually sending technical service personnel to 13 major automobile manufacturers in China. Meanwhile, R&D personnel have also been sent to overseas direct supply customers to conduct cooperative researches.

2.6.2. The quality consultation hotline, which was set up by Baosteel Technology Department on behalf of the Group Corporation, has been receiving high comments from the customers due to the faithful fulfillment of its service commitment.

3. Practice and achievements of Baosteel's technological innovation

Baosteel's technological innovation history can be summarized as follows:

- Phase I - Acquisition from a high starting point.
- Phase II - Collaborative design and manufacturing.
- Phase III – Indigenous innovation.

Implementation of the tenth 5-year-plan further brought in a new stage where overall indigenous innovation becomes prevailing and the innovation findings are widely utilized, especially in the fields of mathematical model and new steel grade development. Even equipment manufacturing is based on the application of proprietary technologies and supplied to domestic markets.

3.1. The burden system has been optimized, which makes Baosteel one of the most competitive steel companies in the world in terms of the hot metal cost.

3.2. Baosteel's PCI has reached 200 kg/tonne and above, setting the record for the international PCI technology.

3.3. Lining life of converters has been significantly prolonged due to the successful development of "slag-splashing process for converter protection." The campaign of Baosteel's No.1 converter has exceeded 14000 heats.

3.4. The innovative process of "converter slag-proposal" hit the world record, which results in dramatic cost reduction and improvement of the environment.

Through the fruitful research on "the process of pure steel making," Baosteel keeps the components of S, P, N, H in steel under 55PPM, and improves the quality of molten steel to ensure the production of pipeline steel and IF steel.

The pipeline with high toughness has been developed successfully at Baosteel, exported to Sudan, Turkey, Pakistan and some other countries in the hundreds of thousands tons. Baosteel's pipeline is playing an important role in China's West-East Gas Pipeline Project.

Baosteel triumphantly implements the completely continuous rolling of regular materials on its cold-rolling mill 2030. The GPS technology has been successfully applied to control the transit of steel at the plant.

In March, 1998, Baosteel launched the integrated production and marketing system. In 2001, Baosteel produced 19.135 million tons of crude steel. Its sales income hit 71.44 billion yuan, and the profit totaled 4.16 billion yuan. Baosteel also applied for 166 patents at home and abroad, among which 103 patents were authorized. Baosteel had 23 registered software copyrights, 328 pieces of know-how examined and approved.

4. Baosteel's new stance after China's entry into the WTO — A brief introduction of ESI

After China's accession to the World Trade Organization, Baosteel faces both opportunities and challenges. In the circumstances, the main task for Baosteel is to enhance its own competitiveness, and then, Baosteel Co. took the lead in implementing Enterprise System Innovation (ESI) program.

With the goal of "being the most competitive steel company in the world," Baosteel should set up the modern operation philosophy that focuses on the customer demand, and change every activity originally diverging from this philosophy. In order to unify the recognition and action at Baosteel up and down, we named this program ESI, short for Enterprise System Innovation.

The ESI of Baosteel has meanings of 3 levels, firstly, bring forward the innovative plan of reorganization and guided by the target of the ESI program, implementing the complete reorganization of the operation flow at Baosteel Co., through analyzing the current operating status; secondly, rebuilding the structures based on the requirement of the operation flow after being reorganized; finally, establishing the related computer information management system, providing enough supports, to realize the new operation flow.

The Target of ESI

- We has already built up the integrated production and marketing system with the finance management as the core, integrating Baosteel's management information and systems including marketing, technology, production, and financing, among which, marketing and production take the priority. Therefore, instead of starting from scratch, Baosteel's ESI program is being fulfilled at high starting to update and expand the former system. Nowadays, the ESI program is to establish an enterprise operation system, adapting dynamically to the outside changes, responding rapidly to the external environment, communicating efficiently in the company, and speeding up the decision-making, embodies the modern "customer centered and driven" philosophy, vigorously pushes on the transparentization management, which improves the empowerment and the traditional management.

- ESI is being conducted at several sectors, such as production and marketing, R&D, financing, purchasing, equipment and energy, environmental protection, human resources. It comprises of 3 phases: breakthrough, comprehensive implement, and systematical integration.
- The consequences of the ESI are the following: reducing the lead time, shortening the R&D period, enhancing the efficiency of management, increasing customer satisfaction, cutting costs, and reinforcing Baosteel’ s competitiveness.

5. Some suggestions

Firstly, as technological innovation has rich meanings, state government should enact some policies to coordinate all related sources. The separate management of science research and technological reformation, plus inconsistent policies, may hinder the expenditure and capital management in an enterprise.

Secondly, the scientificity and reasonability of assessment and evaluation of technological innovative achievements and researchers should be highly stressed, and the evaluations of traditional industries and high technology industries should be distinguished.

Global Technology at GE

Lonnie Edelheit
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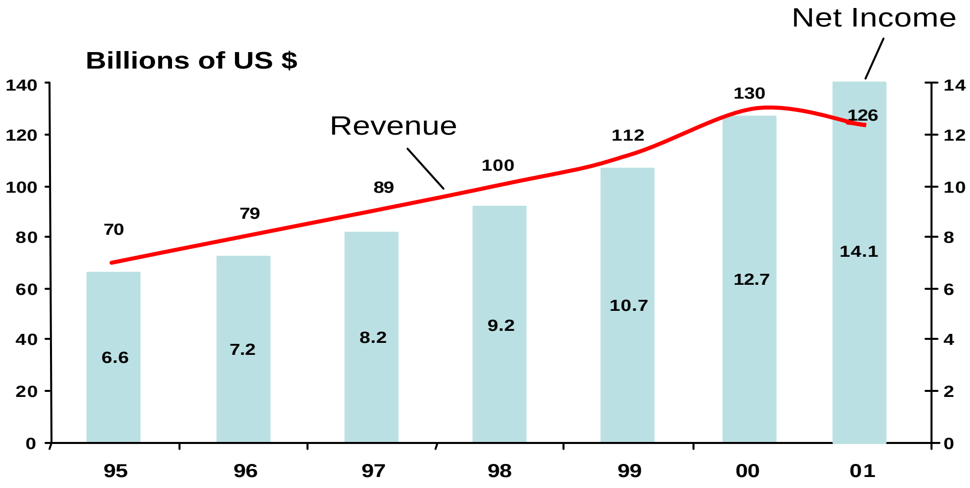
1. GE overview

General Electric (GE) was founded about 125 years ago by Thomas Edison, a world famous inventor. Today, GE is a $126 billion high-tech growth company. Technology is key to growth in GE’s remarkable history. As a diversified technology, manufacturing and services company, GE is committed to achieving technology leadership in each of its key businesses. GE’s state-of-art products, services and technologies, span a wide range of businesses and industries including Aircraft Engines, Appliances, Capital Services, Industrial Systems, Information Services, Lighting, Medical Systems, Plastics, Power Systems, Transportation Systems, Specialty Materials etc. (Refer to Fig. 1, GE’s finance performance from the mid 1990s)



Strong Top and Bottom Line Growth Continues

Figure 1 GE Performance

What makes GE a winning company? GE thinks the following facts are a unique blend of strengthens for growth: diversity of businesses, the unique culture, financial strength, growth initiatives, size, values, innovation and technology, and the most important one: talented people. GE's growth initiatives focus on the customer, they include globalization, services, digitization and Six Sigma quality.

2. GE Technology in China

GE started its activities in China since the beginning of the 20th century. In 1910, GE's products such as electric fans, refrigerators, and steam locomotives were sold in China. In 1925, GE invested in the Shanghai Electrical Power Company, which was the largest foreign venture in China at that time.

GE re-established its business contact with China through the opening of a representative office in Beijing in 1981. GE Hangwei Medical Systems was established in Beijing in 1991, which is the first JV of GE in China. Since the 1990s, GE accelerated its collaboration with China. GE (China) Co. Ltd. was established in 1994, acting as an investment vehicle for GE's projects in China, and providing services to GE's JVs and affiliates. Besides business activities, GE also started research and development in China. In 2000, GE established a research center in Shanghai as part of its Global Research organization. Today, all of GE's businesses have activities in China. With 8,700 employees and $2 billion of revenue in China in 2001, GE has maintained a 30% growth rate in past few years. Sourcing from China increases annually from 50% to 70%. Now GE has 200 Power Systems technology turbines in China. GE's Aircraft Engines (CFM56) have the best reliability record, and GE owns the No.1 technology lighting business. GE has also established 2 state-of-art plastics compounding plants and a Global Center of Excellence of Medical Systems. GE's Global Research in Shanghai is a great success.

Fig 2 is a distribution map of major GE investments in China.

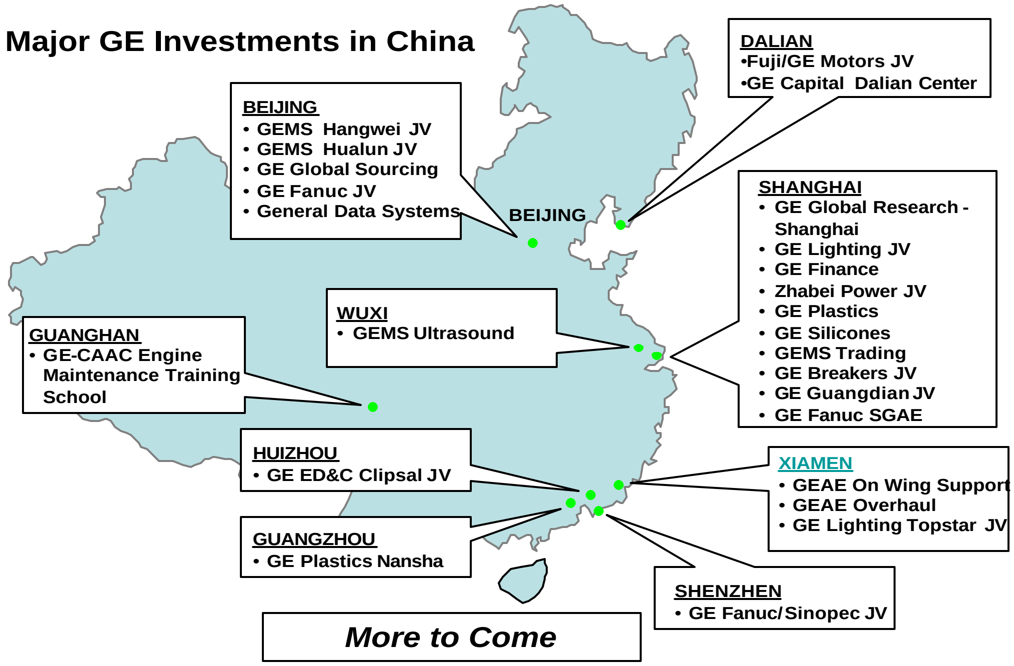


Figure 2 Major GE Investments in China

According to GE's view, in the next 10 years China will become the largest consumer market and a No.2 or No.3 industrial market, the hottest healthcare market as well as the largest consumer finance market. GE also thinks China will be a No.1 aircraft market and the largest power consumer.

GE research facilities are located all over China. GE Global Research (Shanghai), the GE Asia Lighting Technical Center as well as the GE Plastics Application Development Center are all located in Shanghai, with 50, 80 and 50 employees respectively. Located in Beijing, GE Medical Systems CT, X-Ray Engineering Center employs 150 people. GE Medical Systems Ultrasound Engineering center in Wuxi has 50 people. Furthermore, a new, multi-business research facility is to be built in Zhangjiang High Tech Park in Shanghai's Pudong New Area.

Global Research (Shanghai) is a window to GE China's technology development. It is a state-of-the-art research center established in 2000 with less than 20 researchers. Now it has about 50 young talents, 70% of them have Ph.D. Degrees. They are responsible for leading and executing major research programs.

GE's research branches have core technologies of the Global Research organization. GE Global Research (Shanghai) owns key technologies such as lighting power & control electronics, single phase power quality, re-engineering of metallic components, single crystal detector materials & characterization, permanent magnets, phosphor process and manufacturing development.

In addition to these core technologies, GE developed a series of research collaborations in China. GE's strategic research and development partners include Baotou Institute of Rear Earth Elements that focuses on permanent magnet materials, Northwest Institute of Non-Ferrous Metals that focuses on NbTi material, Shanghai Institute of Ceramics and Bright Crystal Technologies Company that focus on scintillator ceramics, as well as Shanghai Institute of Optics and Fine Mechanics in the field of crystal growth.

GE also sponsors many Universities in China in long-term research. GE supports Zhejiang University in power electronics and re-engineering studies. The University of Science and Technology of China is collaborating with GE in the field of laser materials processing. Tsinghua University has a good relationship with GE in the field of motor fan design for aero and noise control.

3. Global Research

Global Research is a core part of GE's organization. GE has about 2,200 global research staff worldwide, more than 750 of them have Ph.D degrees. The Global Research staff represents about 12% of GE's total R&D population and accounts for 30% of GE's patents. This Global Research organization has diverse technical disciplines, with 18% in chemistry, 18% in electrical, 17% in mechanical and computer science, 9% in physics and 21% in all others.

GE has a long history of technology leadership. GE's first research center was founded in 1900 in Schenectady, New York by Charles Steinmetz. It was the first central industrial research lab in the United States. Today, the center is recognized as the cornerstone of GE's commitment to technology.

The mission of GE's global research is to become the center of GE technology and team with businesses to ensure market leadership in products and services. Global research also provides short-term technical support and shares technology across businesses. It will source the world's best technology, attract and develop GE's technical resources and leaders. More importantly, it invents game changing technology.

Ownership, trust and communication are crucial needs for a global organization, and are integral components of GE's technology globalization strategies. GE offers two models of globalization organization, the mentoring model and the center of excellence model. Mentoring model is necessary in early stages, but center of excellence model represents the best use of global talents, and is the globalization philosophy that is used today. In both models, visible global leadership is vital.

To reach best practices of globalization technology, GE believes it is important to grow the global team with mentoring and try to keep the team structure simple. Also, developing unique capabilities at each site, growing the technical capability and taking on strategic challenges at each site are also critical for successful global operation. These research units must have transparent organization to customers, with channels to bridge the differences. In order to improve the productivity of employees, the company must keep high expectations across the board, and make sure leadership is accessible to the global staff. Above all, the organizations should maintain seamless communication between different units and functions.

Analysis on Value Chain and Technological Innovation of Chinese Telecommunication Industry

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1 Value Chain in Telecommunication Industry

The concept – value chain was put forward by Porter when he analyzed corporate competitive strategies. He believes that in the course of value increase exist internal and external value chains of an enterprise. To understand the telecommunication industry, we apply this concept and work out a telecommunication industry value chain as Chart 1. Generally speaking, to view a specific industry as a whole, we are supposed to analyze the whole process of its products or services from production to consumption and to understand the industry from the angle of value increase.

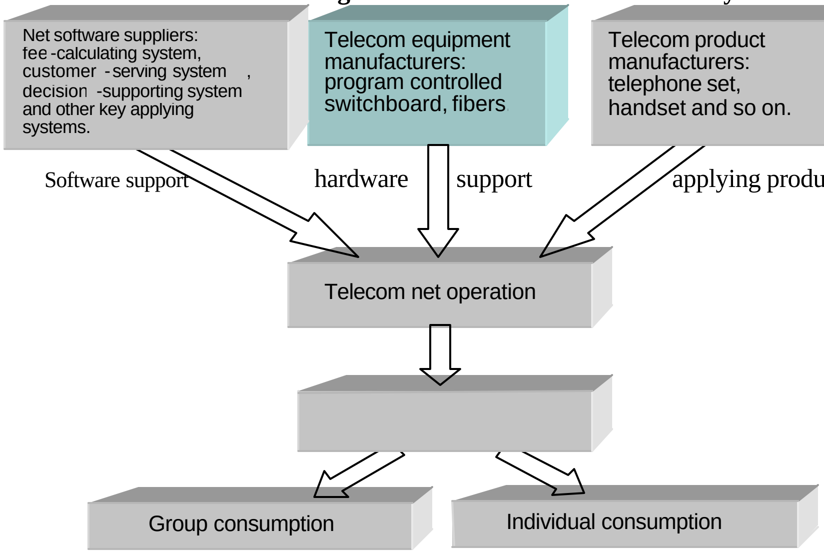
The main body demanding telecommunication services may be divided into two sorts – teams and individuals. Before they provide services for consumers' use, a telecommunication enterprise must be supported by serials of conditions – before its ultimate products enter the market, it must be supported by those mid-, up- and down-stream enterprises producing software's, hardware's, net infrastructures and telecommunication products. For hardware support, it must be supplied with basic equipments by manufacturers. For software support, it must obtain from software designing enterprises those solutions to satisfy customers such as fee-calculating system, customer-serving system, which are key applying systems to sustain telecom service and also important tools to improve service quality, reduce fee disputes and upgrade operational efficiency. The net infrastructures mainly refer to public telecom exchange nets such as immobile telephone net, mobile telephone net as well as those basic net equipments and facilities upgraded on the basis of the above public nets. Service development means applying net facilities to provide customers with available services including mobile telephone, immobile telephone, IP telephone, data transmission special-line surfing and so on.

Among all telecom enterprises in the world, there are hardly any cases of vertical integration of telecom operating and equipment manufacturing. Chinese telecom equipment manufacturers and operators are split. They are located apart on the upstream and the downstream of the industrial value chain.

In reality, owing to the radical development of information technology, telecom operators put much stress on their corporate core competence in market competition. Most of them rely on manufacturers and software and hardware producers. They are not engaged in R&D of upstream products. They usually integrate net facilities with service development or hire net equipment resources and just concentrate on their services. Therefore, Chinese telecom operating industry musters on the mid- and down-stream. It is a group of enterprises relying on net facilities and service development.

Fig 1 displays the value chain of the telecom industry. It illustrates the relationship of telecom equipment manufacturers with telecom operators.

Fig 1 . Chain of Telecom Industry



2 Chinese Telecom Operating Industry

2.1 The analysis on development of Chinese telecom industry

Since the reformation and opening, Chinese telecom industry has experienced reformation and re-organization of several times and thus has been advancing quickly. Especially during the Ninth Five-year Plan, its position in the national economy has been significantly uplifted and its role considerably increased (See table 1).

Table 1 Basic data of Chinese telecom development

ITEMS	1978	1985	1990	1992	1993	1994	1995	1996	1997	1998	1999	2001
Telecom service gross (100 mil. Yuan)	8.64	20.98	87.09	291	463	688	989	1342	1629	2247	3113	3612
Local area switchboard capacity (100 mil. Yuan)	0.04				0.298	0.493	0.720	0.931	1.109	1.35	1.58	1.99
Nationwide popularizing rate of telephone (set per 100)	0.38		1.1				4.66	6.33	8.11	10.64	13	25.9
Popularizing rate of immobile telephone (set per 100)				0.97	1.46	2.28	3.36	4.49		7	8.4	13.9
Popularizing rate of mobile telephone (set per 100)				0.02	0.05	0.13	0.31	0.56	1.12	2	3.5	11.2
Chinese Internet subscribers (ten thousand subscribers)									16	68	215.7	1736

Compared with that in the year of 1978, Chinese telecom business gross in the year of 2001 went up by 418 times, amounting to 361.2 billion Yuan, annually increasing by over 40% and up to the highest 48.6%. From 1978 to 2001, the national public telephone capacity increased from 400 ten thousand sets to 0.199 billion sets. Telephone subscribers in 2001 increased by 95 million and totaled 3.24 hundred million, among which immobile telephone subscribers increased by 35 million and totaled 1.79 hundred million, mobile telephone ones increased by 60 million and totaled 1.45 hundred million. The national telephone popularizing rate reached 25.9%. The mobile telephone popularizing rate reached 11.3%. Telecom business had been expanded from unitary immobile telephone to mobile telephone, radio page and Internet service. Chinese telecom has grown into the second biggest immobile network and the third biggest mobile one. In service quality, net scale, technical proficiency, business income and other respects, it has achieved qualitative leaps. In 2000, the increase of telecom industry accounted for 2.35% of the Gross Domestic Product. The counterpart of last year was 2.1%.

Main reasons for rapid development of Chinese telecom operating industry:

First of all, the rapid economic development has led to continual increase of per capita income and bigger demand of telecom service. Fig. 2 shows the interrelationship between the growth of telecom industry and the increase of per capita GDP.

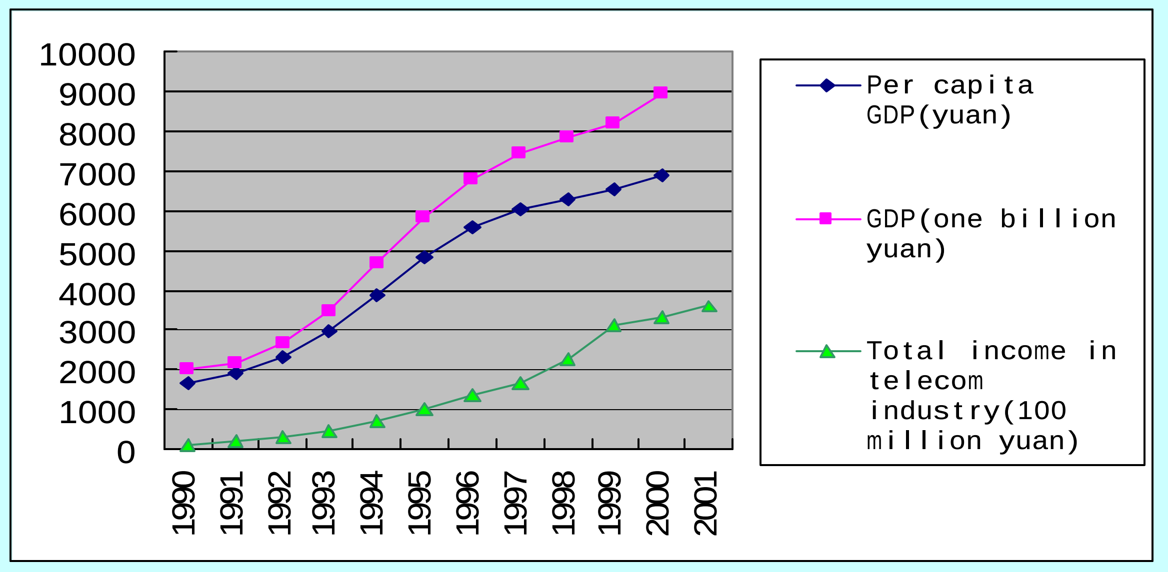


Fig. 2 Interrelationship between the growth of telecom industry and the increase of per capita GDP

Secondly, the vast investment into telecom operating industry has resulted in the faster increase of fixed assets investment and has been supporting the rapid growth of telecom operating industry.

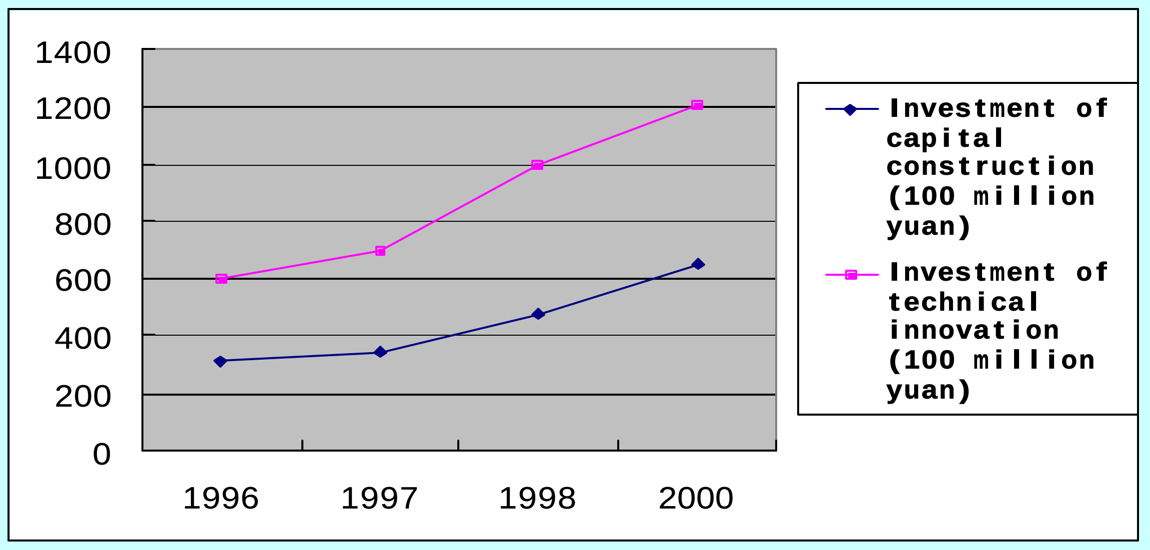


Fig. 3 Increase of fixed assets investment of telecom operating industry

Thirdly, technical advance has been quickened in Chinese telecom equipment manufacturing industry. New technologies have been arising one by one and old ones have been combined. The combination of computer technology with telecom technology is the case. In business, telecom business and net business are also connecting.

Finally, the institutional and organizational innovation in telecom industry has added its competition vigor and thus has upgraded its market performance.

Since the foundation of China, Chinese telecom operation had been monopolized by China Telecom. In 1994, Unicom was founded, dealing in mobile telephone and thus introduced in competition. In February 1999, the State Council approved of the re-organizing project of China Telecom, dividing Chinese telecom business into four parts and establishing China Telecom Group, China Mobile Communication Group, China Satellite Communication Group and China Radio Paging Group. Later, when re-organizing the Unicom, the Council transferred the Radio Paging Group and the whole Railway Communication Company belonging to the original Railway Ministry to the Unicom.

December 11, 2001, China Telecom Group was split into the north part and the south one according to the existing resources. The north part with China Net Communication Corporation Ltd. and Jitong Communication Corporation is re-organized into China Net Communication Group. The south part kept the name, China telecom Group and remained its good will and intangible assets. Two groups were allowed to construct local telephone net and deal in immobile telephone business in the other’ s area and were supposed to provide mutual beneficial services like equal access. The south and north parts respectively obtained 70% and 30% property rights of the national main line transmission net according to their fibers and information channel capacity, as well as all local telephone net of their own area.

After re-organization, the Net Communication, China Telecom, China Mobile, China Unicom, Railway Communication plus the newly founded China Satellite Communication Group are forming a market structure of 5 + 1. Such institutional and organizational innovation has decreased market monopolization, strengthened competitive vigor and upgraded market performance of telecom operating industry. (See Table 2 and Table 3)

Table 2 H.I index of Chinese telecom industry

	1995	1996	1997	1998	1999	2000
H.I index	0.9841	0.9743	0.9399	0.9230	0.40003	0.3647

Before 1999, though competition had been introduced in, the monopolizing situation was not changed and dual monopolization was not formed as expected. The virtual change happened after re-organization in 1999, which led to H.I index reduction of 56 percent, decrease of monopolization and increase of competition.

We will look at its market performance through its labor productivity of the telecom industry. (See Table 3)

Table 3 Increase of the Labor productivity of Chinese telecom industry

	1992	1993	1994	1995	1996	1997	1998	1999	2000
Productivity (ten thousand Yuan)	3.0	4.6	7.1	9.2	11.9	15.5	19.5	38.7	52.6
Increase over the last year （%）	-----	53.3	54.3	29.6	29.3	30.3	25.8	98.5	35.9

From the table, we see that the labor productivity had been raised year by year. The increase after 1994 when competition was introduced in had been steady. Up to 1999 when the telecom market was re-organized, the increase over the last year amounted to as high as 98.5%. All these tell us that competition in domestic market must be strengthened.

2.2 The gap of Chinese telecom operators from foreign ones

While, compared with those developed countries, Chinese telecom operators still have a great gap. (See Table 4)

Table 4 Data of telecom development in some countries

COUNTRY	Popularizing rate of immobile telephone (set per hundred person)	Popularizing rate of mobile telephone (set per hundred person)	Immobile telephone per employee	Telecom income per employee (dollars)
China (2001)	13.9	11.2	114*	36326*
U. S. (1999)	70.88	16.53*	190	203502
Japan (1999)	50.79	51.18	289	48339
Germany (1998)	63.21	7.07*	205	207534

Data origin ：From *Competition Is the Only Way for Telecom Industry* by Tang Shoulian and Cao Ying, published in the 11th issue of *Telecom Science, 1999.*
*Data is for 1998.

At the end of 2001, Chinese popularizing rate of main line telephone was 13.9%, which could not compare with those of the U. S., Japan and Germany. That is, Chinese telecom will be faced severe challenge in the world market competition.

3 Innovation in Chinese Telecom Manufacturing Industry: Technological and Managerial Innovation in HUAWEI

That technical innovation is the root of corporate development has been widely recognized. In Chinese telecom industry, people have built up a strong consciousness that only the independent intellectual property may enable us to gain initiative in the international market competition.

The governmental documents about developing telecom hi-tech have been put on stage. According to aims of telecom technologies made by the Tenth Five-year Plan, Chinese telecom manufacturers are supposed to grasp core software technologies of GSM, GPRS, IS95 – CDMA, CDMA2000-1X and the technology to design mobile terminal chips. They are supposed to make a breakthrough in the technology to develop and manufacture those key accessories and parts.

3.1 Technical and Managerial Innovation in HUAWEI Technologies Co., Ltd.

Established in 1988, **HUAWEI** Technologies Co., Ltd is a private high-tech enterprise fully owned by its employees. **HUAWEI** specializes in R&D, production and marketing of communications equipment, providing customized network solutions for telecom carriers in fixed, mobile and data communications networks.

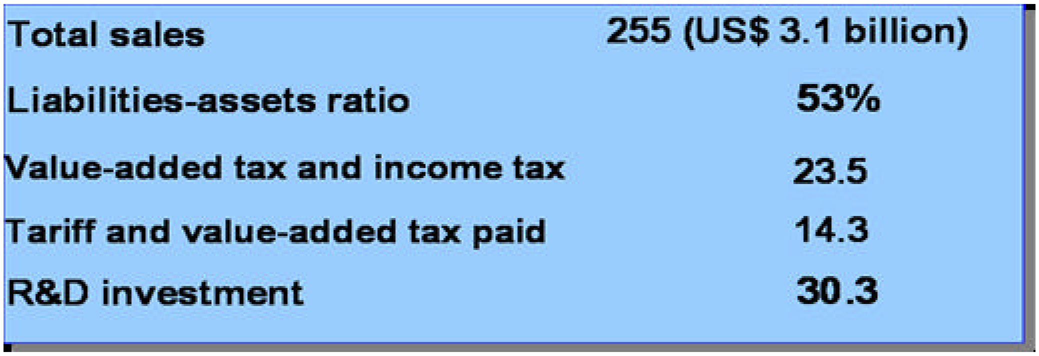
Huawei has turned their science and technology tactics from *researching and developing hi-tech* to *focusing on application.* They use their 10% of their sale for scientific research. They have more than 9000 members engaged in research. In addition to its headquarter in Shenzhen, they have set up research institutes in Beijing, Shanghai, and even in the U. S., Japan, India and Hong Kong.

(1) Personnel structure

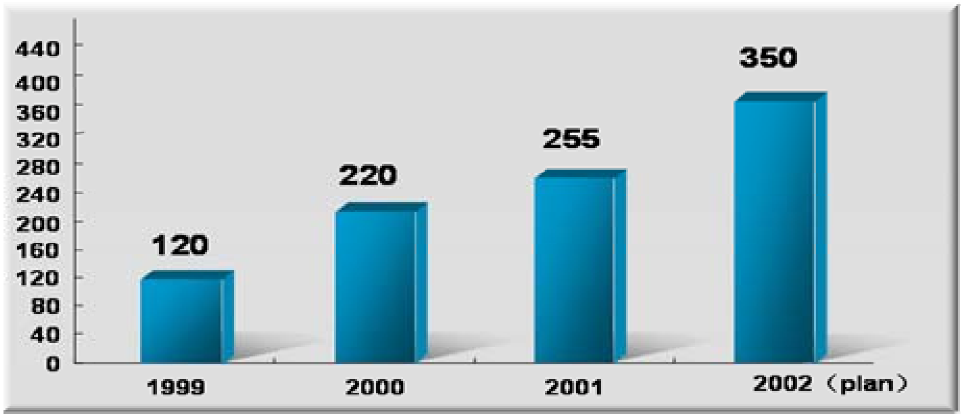
Staff number: 22000, 85% received college education;
- R&D staff: 46.5%
- Marketing and serving staff: 31%
- Managing and others: 9%
- Productive staff: 13.5%

(2) Performance in 2001

Table 5 HUAWEI: Performance in 2001 （hundred million Yuan）



Total sales	255 (US$ 3.1 billion)
Liabilities-assets ratio	53%
Value-added tax and income tax	23.5
Tariff and value-added tax paid	14.3
R&D investment	30.3



- **Sale in 2001 was 255 hundred million Yuan, increasing by 16% over 2000**
- **Sales of such equipments as fiber net, intellectual net, GSM, wide band greatly increased.**

Fig.4 Total Sales increased in HUAWEI

(3) Global R&D system

American Silicon Valley Research Institute
American Dallas Research Institute
Sweden Research Institute
Indian Research Institute
Russian Research Institute
Huawei Technology (headquarter)
Beijing Research Institute
Shanghai Research Institute
Nanjing Research Institute
Xi’an Research Institute
Hangzhou Research Institute
Chengdu Research Institute

- ➢ Technical development and cooperation are globalized. They pay much attention to integrated research of technologies and operational mode.
- ➢ Has become a formal Sector Member of ITU-T
- ➢ Huawei Indian Research Institute is the first R&D institution in China which has acquired CMM four – star international certificate.
- ➢ Huawei TELLIN intellectual net won the first prize of the national scientific and technological progress.

(4) Managerial innovation and core competence

It is beyond neglect to build up core competence of Chinese telecom manufacturing industry, in addition to grasping technologies with independent intellectual property. Huawei believe that the biggest distance of Chinese enterprises from western ones still lies in management. They have put forward managerial aims keeping to the international track. They have invited western consultants for advices in R&D, production, finance and human resources. Working with American HAY, one of the biggest HRM consulting companies in the world, they have introduced in the best job evaluating system and thus have improved HRM evaluating system.

Managerial innovation is of service for product innovation. Managerial cooperation with IBM enables Huawei to have adopted world advanced concepts of developing new products and have established IPD – Integrated Product Development and ISC – Integrated Supply Chain. They have built IT system covering all departments making it possible to transform innovative achievements into products standing market test.

Aims of IPD:

Hard index: cutting developing cycle 15% to 30% in the trial stage, 40 to 70% one year later.

Soft index: arriving at functional stage one year later, making IPD regular and operating the company totally under the new managerial mode.

(5) Independent innovation and open cooperation

They paid much attention to accumulating and protecting core intellectual property. By the end of Dec. 2001, they have applied for 1021 patents including 132 in 3G field. They have applied for foreign or domestic trademarks for 468 times.

(6) Organization innovation of Win-win cooperation

In recent years, Huawei has reached a new height in international cooperation. They have successively formed partnership with more than ten world-famous companies such as Intel, IBM, TI, and MOTOROLA. The cooperation with IBM in the field of paging center and high quality net communicating system enable them to have kept their superiority of Intess customer–serving center, the future–generation IP Router and SDH fiber transmission system.

(7) Main technical advance

HUAWEI Lead in the world in field of SDH phonic net, access net, intellectual net, Internet inletting server and so on. There are great technological advance in Phonic net, Mobile communication, Wide band, Switching and so on.

3.2 Chinese telecom manufacturing industry has a long way to go

By August 2000, China had become the biggest mobile communication market. It will certainly become a big manufacturing country of telecom products. According to the national information center, during the tenth five-year plan, China will invest 500 billion dollars in it. According to *the Tenth Five-year Plan Program for Telecom Industry,* by the year of 2005, total turnover of Chinese telecom manufacturing industry will come up to 350 to 400 billion Yuan. Productive scales of main products will be in leading places in the world. Immobile and mobile telephone net capacity will leap to the top. Telephone subscribers will total around 5 hundred million and almost all administrative villages will be equipped with telephone. Data, multimedia and Internet users will amount to about 200 million and people surfing on net will account for 15% of the whole population.

However, at present, Chinese telecom manufacturing industry still shows its symptoms of low concentration, low scale benefit and weak technical innovative ability. According to statistics, the sum of annual business income of all Chinese telecom manufacturers is even less than that of Nokia alone. China has not yet grasped the technology to produce a handset's most important part – 0.25- to 0.35–micron super-large-scaled professional integrated circuits, which have to be imported. The shortage of the technology above and other core technologies such as the core chip of CDMA and GSM mobile communicating system and fiber-prefabricating club is and will be on the way of Chinese telecom industry, and so Chinese telecom industry has a long way to go.

Conclusion

(1) From the angle of value chain, there are scarcely any enterprise integrated with telecom operating and equipment manufacturing. The telecom operating industry is centralized in the mid- and down- stream of the industrial value chain. It is an enterprise group based on net facilities and services. Chinese telecom equipment manufacturers and operators are separately located in the up- and down-stream.

(2) After reformation and re-organization of several times, Chinese telecom operating industry has gained rapid development. Especially the development during the Ninth Five-year Plan has uplifted its position and increased its role in the national economy.

Mean reasons for rapid development of Chinese telecom industry are as follows: First of all, the rapid economic development has led to continual increase of per capita income and bigger demand of telecom service. Secondly, the vast investment into telecom operating industry has resulted in the faster increase of fixed assets investment and has been supporting the rapid growth of telecom operating industry. Thirdly, technical advance has been quickened in Chinese telecom equipment manufacturing industry. Finally, the institutional and organizational innovation in telecom industry has added its competitive vigor and thus has upgraded its market performance.

(3) Chinese telecom equipment manufacturing industry has gained rapid development through technical and organizational innovation.

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