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Journal:	*Regional Studies*
Manuscript ID:	CRES-2008-0190.R2
Manuscript Type:	Main Section
JEL codes:	R5 - Regional Government Analysis < R - Urban, Rural, and Regional Economics
Keywords:	biotechnology, Innovation, China, R&D

State-sponsored R&D: a case study of China's biotechnology

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(Received August 2008: in revised form October 2009)

Abstract

This paper examines the model of China's biotechnology innovation. We apply the typology of entrepreneurial, partnership, and developmental state, to the Chinese biotechnology sector. Biotechnology development in China originates from state-sponsored programs. Although compared with the major biotechnology firm, Amgen, in the US, China's total product sales only account less than the half, Chinese biotechnology research capacities experience fast growth. The state funding plays a crucial role in the latecomer situation. Geographically, biotechnology industries are concentrated in Beijing, Shanghai, Shenzhen and other major cities. The state promotes biotechnology development through strategic support in its 'Medium and Long term S&T Development Plan', overseas talent attraction programs, commercialization initiatives, and development of high-tech and science parks. However, such a model has its problems: the lack of sustained funding and under-developed venture capital, weak link between research and industry, and under-performed IP output. Faced with the funding constraint, contract research organizations (CROs) have recently become proliferated. Despite the strong role of state, we conclude that the Chinese model of biotechnology innovation is a hybrid one, rather than the classical one of developmental state, which combines various elements of different models.

Keywords: Innovation, R&D, biotechnology, innovation model, China

INTRODUCTION

Innovation is a critical ingredient of national competitiveness, and investment in research and development (R&D) is closing the gap in the production of knowledge between developed and developing countries like China and India. Biotechnology covers agricultural biotechnology, healthcare biotechnology related to drug development, environmental technology and renewable energy. The sector is targeted by many nations as one of the new industries with the highest potential in the 21st century. The industry, more than others, absorbs most of the investment risk and it is believed to lead a new technological revolution. Biotechnology throughout the world is expected to accelerate and reach a new and higher stage of development. In an effort to catch up with the developed world, China and India, as well as many other newly developing and industrializing countries, have focused on biotechnology as one of the prime strategic components of their innovation policies. It is generally believed that an invigorated development of bio-economies of these two countries will have a significant impact on the respective national economies and prompt an upgrading of their industrial structures.

There have been extensive studies of China's innovation system (e.g. Sun, 2002a, Wu, 2007). But most studies focus on the ICT sector (Wang and Lee, 2007) and high-tech parks (Walcott, 2003; Zhou and Tong, 2003, Wei and Leung, 2005). In particular, the innovation process in Zhongguancun, a park based on ICT, has been studied in depth (Zhou, 2005; Liefner *et al.*, 2006). Sun (2002b) found that in-house R&D was the primary source of innovation in large and medium-size manufacturing enterprises in China, although China also imported technologies. The limited effort to absorb imported technologies has become a serious barrier to fulfilling their potential and for upgrading China's indigenous technology capabilities. The organization of R&D activities in China's industrial enterprises is still fragmented with weak linkage between industrial R&D and the domestic technology market (Sun, 2002b). The development of ICT in the past decades was successful in terms of its growth rate. But the business model is copying foreign technology or buying technology and then assembling in China. Over years, ICT has experienced phenomenal growth. It appears to be more integrated in the global production network. Linking with global production boosted the growth of the sector. But most enterprises are not positioned at the upper stream of technology development, but rather acting as assembling and emulating MNC production. This is not to dismiss the entire ICT sector as some leading ICT companies are making headway into innovation. As an initial step, it might be useful to buy technology. The critical issue is to develop innovation capacities. China now strives to promote technology transfer.

In contrast to extensive researches on ICT, relatively few studies are directed at China's biotechnology. With the growing support of government for biotechnology research, China has made remarkable progress in some priority areas such as genomics and biomedicine (Chen et al., 2007). For example, China has generated increasing publications in health biotechnology with average annual growth rate of 23% during the period of 1991-2002. The Chinese Academy of

Sciences and the top universities are the main contributions for the growth of publications. Beijing is the most active city in China, publishing total of 2,472 papers in genomics and 623 in health biotechnology. Shanghai ranked as the second and Wuhan ranked as the third in terms of the publications in these two areas (Science-Metrix, 2004). But the citation of Chinese publications is generally lower than the average level in the world. However, in the recent years, Chinese scientists have published many high-quality papers in the top journal in the world, such as *Science* and *Nature*. The significant number of high-quality publications is resulting from the international collaboration (Yu, 2007).

Biotechnology, owing to the significant amount of investment needed, is driven initially more by state sponsored programs. Such an approach allows more technological orientation from the beginning. On the other hand, it raises a question of whether the state can sustain its investment in the long term, because investment in biotechnology is extremely intensive and it takes a long time to see economic return. The purpose of this paper is to examine China's biotechnology in the context of overall R&D strategy in China. We describe the development process of state-sponsored biotechnology and the strength and limitation of such an innovation model.

This paper is organized as follows. The next section presents the typology of three biotechnology innovation models in the world. Then, China's biotechnology development is examined with respect to the R&D environment. We then discuss specifically the role of the state in the state-sponsored approach. Next, we analyze the limitations of this model. Finally, we discuss recent changes in this state-sponsored model. Finally, in the conclusion we summarize major findings and compare the Chinese biotechnology innovation model with the theoretical framework.

THREE MODELS OF BIOTECHNOLOGY INNOVATION

According to Cooke *et al*. (2007), there are three models of innovation: entrepreneurial, partnership and developmental state. These innovation models are closely related to their respective economic development models: the liberal market-oriented, regulative and state-centred economy. These models differ in terms of economic coordination, labour market, education system, capital and financial markets, and R&D systems. We analyze China's biotechnology in relation to these three models.

The entrepreneurial model

The entrepreneurial model is associated with the liberal market. The US liberal market is believed to accommodate business organization and innovation styles and strategies. Best coordination of the economy relies on market mechanisms. The flexible labour market allows job mobility between firms. Built upon a competitive ethos and economic individualism, the entrepreneurial model emphasizes creative or scientific novelty hedged by intellectual property rights. Job mobility is based on risk taking and abundant opportunity in the region (Florida, 2002). The R&D system is characterized by strong university-based R&D. In the US, this is coupled with state-sponsored healthcare and defence-oriented R&D. However, the state programs do not substitute market-initiated selection. R&D is based on the private sector. Or more precisely, these programs are executed through the market. Corporate governance is based on private ownership (Whitley, 2000), which allows a high level of flexibility and enables shift response the market signals. Outsourcing and subcontracting based on competitive tendering is becoming popular business strategy in high-tech industry to maximize efficiency. The US model is a more typical entrepreneurial one, while the UK economy is considered as a variant on liberal market.

The public-private partnership model

The model is associated with rule-bound and legalistic regulation of economic activity. The state negotiates with and delegates social and economic functions to private associations. The business and industry associations are key intermediaries regulating competition between business partners and facilitating collaboration. This devolves into forms of self-management, which localize economic development and political stability (Cooke and Morgan, 1998). Many continental European economies, from Germany through France, Switzerland and the Nordic countries operate this partnership model of economic organization in which interaction occurs by negotiation across boundaries between otherwise divergent interests associated with government, industry and labour (Cooke *et al*., 2007). The partnership model reinforces long-term cooperation among economic actors, emphasizing growth goals and the continuous exploitation of knowledge in established technologies. The business system usually combines a high level of ownership integration with strong inter-firm linkages (Whitley, 2000).

Risk sharing is common between companies and there is cooperation among competitions in training and technical support assisted by industry associations and other intermediaries like chambers of commerce and industry. The capital market is credit-based, characterized by close links between banks and companies, including interlocking board-membership. Banks typically provide long-term investment with relatively low long-term risk. They are reluctant to finance risky, more entrepreneurial projects. The R&D system involves universities and public research establishments, often in cooperation. Cooperation with large and smaller enterprises also enables innovation gains from research findings to filter through the innovation chain rather than awaiting mainly entrepreneurial impulses from market signals. The governance played an important role through innovative policies to develop region-based industries. However, recently European economies began to learn from the US entrepreneurial model. For example, the Gate2Growth initiative, launched by the European Commission's Directorate General Enterprise recently, aims to encourage innovation entrepreneurship through provide access to private innovation financing and tools for better knowledge exploitation. It will contribute to the strategy to increase the competitiveness of knowledge economy in EU (http://www.gate2growth.com/).

The developmental state model

In the newly industrializing economies, the developmental state model is widely practiced to 'catch-up' western economies. The social context is state-centric, different from liberal and coordinated markets. Exemplars of the developmental state 'big-push' model are Japan and South Korea. The developmental states are plan-rational rather than market-rational, which is characterized by a strong, authoritarian, central government. The developmental state deliberately and strategically supported large enterprises and industrial competitiveness. The emphasis is on export-orientation. Over time, the policy shift is from trade policy, to industrial policy and more recently to innovation policy. There are many similarities between Japan and

South Korea. But Japan is more a case of 'state-guided' coordination, whereas South Korea is 'state-organized system'. The Japanese model encourages the banking sector to support strategic industrial sectors; Korean model expands the scope to involve the private-sector. While the banking sector is similarly important in Korea, large corporations known as *chaebol* play an important role in innovation. South Korea also sees greater government deregulation of the industry and promotion of technology transfer in public universities to the private sector.

Corporate governance in this developmental model is characterized by a high level of state-controlled ownership and coordination (Whitley, 2000). The state controls the capital market; banks are mostly state-owned and provide favoured financial support for targeted large enterprises. Because of a low level of public funding in basic research and the weak position of universities in the national research system, science-based industries are weakly developed, for example biotechnology. Formal linkages between university and industry are underdeveloped, leading to a lack of academic spin-offs and technology-oriented start-ups (Lam, 2002).

Comparing these three models, we find the entrepreneurial model is more flexible and responsive to market signals, and hence adjusts more effectively, whereas the partnership model may out-perform liberal market ones in periods of economic stability and stable global trading patterns. The developmental state model can achieve certain strategic objectives and identify key sectors for growth and industrialization (Keeley, 2003). It can implement a long-term vision through top-down policy but the mechanism of coordination is more rigid.

The developmental state and biotechnology

The biotechnology sector has its specificity: it is a capital intensive sector. Some pioneer biotechnology companies such as Amgen and Genentech developed on the basis of scientific research and then commercialized their products, leading to the establishment of multi-billion dollar biotechnology industry. But investment in biotechnology is very intense. Compared with ICT, it has a longer term of capital return, and higher risk. It is extremely challenging for national government to sustain such a high level of investment for such a long term. From an innovation idea in a laboratory to a product by the biotechnology company, it takes 12 years and US$802 million on average to develop a new drug (DiMasi et al., 2003). Usually there is a need to expand the source of investment to include venture capital. The ultimate challenge for the developmental state model is whether its investment in the sector is sustainable.

Because of the specific nature of biotechnology development, for the latecomers, the developmental state model has been used to catch up biotechnology development. In biotechnology, Singapore represents the most aggressive developmental state model. Singapore *Biopolis* is known for the intense government input. The *Biopolis* is dedicated to biomedical R&D and designed to foster a collaborative culture among the institutions present and with the nearby National University of Singapore, the National University Hospital and Singapore's Science Parks. The policy is to build a biotechnology cluster around foreign direct investment (FDI). Singapore has done well in other sectors such as petrochemicals, electronics and ICT using the same approach.

Singapore government biotechnology initiatives started in 1987 with the establishment of the Institute of Molecular and Cellular Biology at the National University of Singapore. During the period from 2000 to 2004, investment in developing biotechnology intensified (Lim and Gregory, 2004). Four new institutes in bioinformatics, genomics, bioprocessing and nanobiotechnology were developed at a cost of US$150 million. Public venture capital of $200 million has been committed to support start-ups and to attract FDI. A further $100 million is earmarked for attracting global leading corporate research centres. Internationally celebrated scientists have been attracted, such as Nobel laureate Sidney Brenner, Alan Colman, leading transgenic animal cloning scientist from Scotland's Roslin Institute, Edison Liu former head of the US National Cancer Institute, and leading Japanese cancer researcher Yoshaki Ito (Cooke., 2007). Singapore has attracted big pharmaceutical companies such as Merck, Pfizer and Glaxo to set up manufacturing or clinical research service there. Its policy stimulates cluster growth as an offshore research and production platform targeting the burgeoning Asian market (Finegold *et al*., 2004). The outstanding feature of Singapore model is its public funding in biotechnology, headhunting foreign talent, and stimulating indigenous spinout activity.

CHINA'S R&D AND BIOTECHNOLOGY DEVELOPMENT

Significant increase in R&D investment

China, the world's largest emerging economy, has become the important player in R&D activities. China was estimated to spend over $136 billion on R&D in 2006, measured in purchasing power parity (PPP), only after the US (Duga and Studt, 2006; OECD, 2007a). In 2005, Chinese investment in the total volume of PPP was equivalent to Japanese R&D investment, but the investment in R&D accounts was only 1.4% of GDP (Table 1). This ratio is still far below the US figure of 2.6% and 3.2% of Japan. Nevertheless, it is on the trajectory of growth, increasing from just over $17 billion in 1996 to $136 billion in 2006, even faster than the economy growth rate of 9-10% a year (Figure 1).

[Table 1 is about here]

[Figure 1 is about here]

China's investment in R&D presents two different pictures, depending on whether the real term or PPP is used. PPP terms will significantly inflate China's investment. For example, in real terms China invested $30 billion in 2005, while PPP measure increases the figure to $124 billion, a four times inflation. Jakobson (2007) uses real term measure, while OECD report (OECD 2007a) presents a picture of PPP. It is not entirely proper, in our view, to use PPP exchange rates to measure R&D investment, because some input in R&D such as consumables in biotechnology experiments are internationally priced, though salaries to researchers and scientists are low because of higher purchase power of Chinese currency. Even for the latter, to attract global talent, some living expenses are priced not according to the system of local price, for example international school for the children of expatriates is very pricy (at a typical annual fee of $20,000, compared to nominal charge of the local school). Using PPP is therefore not proper. It could exaggerate China's funding capacity in R&D, as currently state funding dominants the capital source for R&D.

China's increase in R&D investment has two implications. First, as a developing country, China is catching up in R&D investment. The economic growth model has moved from a simple labour intensive approach to knowledge investment. This increase in R&D activities is reflected in the recent policy emphasis on 'indigenous capacity of innovation', namely China needs to have its own IP-protected innovation and products (although the production of IP protected products could be achieved through joint ventures). Second, despite the significant increase in R&D investment, there is still a funding gap. The ratio of R&D investment to GDP is still low. This questions the state's capacity as the sole funding source of long-term R&D. The Chinese government aims to increase R&D investment in the next decade. The target is to increase R&D to 2.5% by 2020 (OECD, 2007a).

In biotechnology, China's initial development was driven by the food demand of a large population. Its population accounts for one fifth of the world total, whereas its arable land area only occupies 7% of the world arable land (Chinese Academy of Agricultural Sciences, 2007), China's biotechnology has emerged largely because of beneficial state policies and increasing funding through innovation programs. Table 2 showed the global biotechnology development comparison[1]. The key indicators on biotechnology companies show that the US has greater advances than Europe (EuropaBio, 2006). In the US, there are two world-leading biotechnology clusters: greater Boston region and San Francisco-San Diego Silicon valley. In Europe, the UK leads biotechnology. In the UK, Cambridge and Oxford are the main clusters. Edinburgh-Glasgow is a new biotechnology region in Scotland. Germany and France are the after main biotechnology countries in Europe. In Sweden, biotechnology is growing fast with the strong pharmaceutical industry. In developing countries, India and China have just started their biotechnology development.

[Table 2 is about here]

[1] To be consistent, the biotechnology companies in the table only included the main biotechnology companies, excluded the big pharmaceutical companies for whom biotechnology is an important, but minor part of their business (OECD, 2006b). The data about China biotechnology come from different sources; some figures may be different depending on the definition of biotechnology.

In terms of the number of firms, in the US, there are nearly 2,000 biotechnology companies with 190,000 employees, generating over $56 billion of revenue (Table 5). In 2004, the US spent over $28 billion in R&D. These figures are far above the numbers in other countries. In China, there were over 500 biotechnology firms with employment of 50,000 (CNCBD, 2007). The UK has the same number of companies but with less than half of employment in China. The UK showed more capital efficiency in terms of the ration of revenue generated from its R&D expenditure. It generated more than 50% revenue in the UK than Germany with similar expenditure.

It was estimated that, the Chinese central government spent over US$1.8 billion in total on biotechnology during 2000-2005, while enterprises were estimated to spend about $60 million (see Figure 2). The sales of biotechnology were valued about $2.1 billion (CNCBD, 2007; Chong, 2005). Other sources reported that the sale of biotechnology pharmaceutical products grew from 10.8 billion yuan in 2001[2], to 16.6 billion yuan in 2002, and 22.9 billion yuan in 2003 (CEI, 2005: 82). It was also suggested that the sale could be as high as 30 billion in 2003 by Shanghai Jiaotong University (SJU, 2006). According to National Development and Reform Commission (NDRC), the sale value reached 30.2 billion from January to August 2007 (Hu, 2007). From this, we can estimate that the sale value may reach 45.3 billion Yuan in 2007, equivalent to $5.66 billion. But the definition of biotechnology is still ambiguous in China, and very often it is difficult to separate it from biotechnology pharmaceutical companies. In 2006, the largest biotech Amgen had product sales of $13.8 billion with R&D investment of $3.2 billion. The total product sales in China's biotechnology only account for 41% of the sales of a single (but the largest global) biotech company, Amgen.

R&D organization and programs

In terms of biotechnology R&D management, the State Council Steering Group for Science, Technology and Education is a top-level co-ordination organization of the central government (Figure 2). The Ministry of Science and Technology (MOST) plays a prominent role, working with a number of ministerial level agencies – Ministry of Education, the National Natural Science Foundation of China (NSFC), and the Chinese Academy of Sciences (CAS). MOST

[2] Because the sector is relatively new, there was no statistics about the sector before 2001.

works with the Ministry of Agriculture (MoA) to promote the agricultural biotechnology; with State Food and Drug Administration to develop drug biotechnology; with Ministry of Human Resources (MoH) to attract talents from abroad; with Ministry of Finance (MoF) to encourage the innovation in enterprises. Regional governments also play a significant role to support the implement of the top-down innovation policy (CNCBD, 2007), in terms of regulation and resources, especially financial contribution for match funds. Usually regional governments are required to provide match 40% of total funds. For example, the local government contributes US$125 million to biotechnology programs (see Figure 2).

[Figure 2 is about here]

Enterprise, university and research institute are the three R&D performers (Figure 3). Enterprise is the main actor in R&D, sharing 62% of total R&D expenditure and 63% of total patent applications in China in 2003. It focuses on technology development and technology marketing. It also received the largest percentage of government funding, reaching 60%, while university and research institution received the similar percentage of 18% of government funding, according to OECD report on China's innovation policy (OECD, 2007a). Large and medium firms are the major R&D players among the enterprises, while small and medium enterprises (SME) are active in R&D in the developed countries such as US. But in general, the enterprises in China, especially in ICT, have invested in importing technology more than in developing their own R&D capabilities because of the lack of effective incentives for R&D performers to enhance their innovation capacity (Chang and Shih, 2004). Industries have not broken out of the low-value added production.

[Figure 3 is about here]

The public research institutions have been downsized and rebalanced in favour of universities, which aims to improve the research quality. A large number of research institutions have been reformed into private companies since the mid-1980s (OECD, 2007a). Today, the research institutions started to focus more on applied research and technology transfer. They play a key role in mission-oriented research, mainly in the natural sciences and high-tech-related disciplines.

Universities are still focusing on basic research and not active in technology development and market. Universities are considered to have the greatest potential for developing a world-class research and innovation. China's government policy has increased the funding on universities, especially top rank universities such as Beijing University and Tsinghua University. The increased funding for R&D seems to work efficiently in terms of scientific publications, ranked as the fifth in 2005 in the science citation index (SCI) (OECD, 2007a). Until recent, universities have been urged to extend research applications and more spin-off enterprises are created within university, science or high-tech parks.

In order to speed up R&D, the Chinese government has launched a series of programs (Table 3). Since the 1980s, China has devoted a large amount of funds and human resources in R&D through the program such as '863 program', the 'torch' and 'spark' programs. The '863 program' was set up by MOST in 1986. The program is a national high-tech program, focusing on applied science. Biotechnology is at the top of several key areas. The 863 program was mapped with national five-year plans. Since then, the vision of biotechnology future has seen part of overall national modernization plan (Keeley, 2003). There are other sources of funding for biotechnology, including NSFC. The '973 program' is for basic research (Hu and Jefferson, 2004). But these funding sources were mainly distributed among small but well-connected science-policy-business network (Keeley, 2003). From 1995, the Ministry of Education decided to increase funding to 100 major universities to build '100 universities in the 21st century', known as '211 Project'. Subsequently, from 1998, it allocated special funding to the first 34 universities (later increased to 38) with the hope to build the first rate world research universities in China, known as '985 project'.

[Table 3 is about here]

STATE-SPONSORED R&D MODEL

In this section, we examine various features of state-sponsored R&D model. We first reveal the role of state in strategy formulation, and then discuss dominance of state funding in R&D. Next, we examine the state's effort to attract overseas returnees, and finally analyze the development of high-tech parks as critical sub-national R&D space.

Strategy formulation

In terms of strategy formulation, the publication of 'Medium- and Long- term S&T Development Plan' in 2006 is a milestone of R&D development in China. The plan recognizes the need to develop 'indigenous innovation' capacity. More specifically, it aims to reduce the reliance on foreign patents and enhance the mastering of core technology; the plan proposes to develop several world-class universities and research institutions (Serger and Breidne, 2007). Chinese government designs strategic plan and then uses the plan to allocate funding and R&D activities in relevant institutes (Chang and Shih, 2004). The system of education and innovation encourages universities to interact with industries and promote innovation capacity. The plan identifies 11 key fields, 8 frontier technology fields, and 69 prioritized subjects where technology should be developed with Chinese ownership of IP. Biotechnology is identified as one of eight frontier technology. The plan recognizes the current problem of over-reliance on foreign technology (Jakobson, 2007). The ICT sector is more problematic, because the level of 'indigenous inventions' is still low. Biotechnology sector starts from government sponsored programs and might provide an alternative model of innovation that fits better within the requirement of the Medium and Long Term S&T Development Plan. Table 4 shows the strategic areas in biotechnology specified in the Plan (Yu, 2007: 136). The areas include drug target discovery, stem cell-based human tissue engineering, to industrial biotechnology. The Plan is to develop an indigenous capacity, as is mostly emphasized in biotechnology.

[Table 4 is about here]

Dominance of state funding

The state funding is a critical source of biotechnology R&D, which demonstrates a marked dependence upon government support with limited private enterprise support. This contrasts markedly with the US and the UK. Private venture capital and business angels are the main financial resources for start-up biotechnology companies in the liberal market countries. In China, government programs are important source of funding. Table 5 indicated around 20-30% of "863 program" budget have been allocated to biotechnology development in China. Also, biotechnology shared about one third of NSFC funding during 2001-2005 (Figure 4). This demonstrated the priority of biotechnology in the national innovation policy. But different from developmental state, the Chinese government also encourages the setting up of private enterprises. The nation's public-dominated research system has also given China's researchers a strong incentive to commercialize their researches. The government has the power to give researchers full support for their research commercialization, not only financial support but also regional control regulation. Local governments such as the municipality of Shanghai also play a critical role in the development of biotechnology through preferential policies.

[Table 5 is about here]

[Figure 4 is about here]

This state funding model works well with China's historical strength in basic scientific research. Despite a new sector, healthcare biotechnology and plant-agricultural biotechnology have a strong scientific research record in China. Chinese scientists have successfully developed chemically synthesizing bovine insulin-important in diabetes treatment in 1965. China was the only developing country involved in the Human Genome Project. The Chinese National Human Genome Centre located in Shanghai and Beijing Genomics Institutes are involved in the project. Through the state of art sequencing equipments, these institutes decoded the rice genome of predominant rice species in China. China also developed research in vaccine, diagnostics and therapeutics. The area covers the antibody research, notably related to severe acquired respiratory syndrome (SARS), gene therapy, functional genomics, and stems cells (Li *et al*., 2004). In stem cells research, Chinese research institutions are working on adult as well as embryonic stem cells and cell reprogramming. In 2003, Shenzhen SiBono GenTech was the first firm in the world to obtain a drug license for a recombinant gene therapy (Li *et al*., 2004). The product (Gendicine) is aimed at treating head and neck cancer. The clinical trial took 5 years and costs the company more than $9.6 million to develop, in addition to research grants from the government.

Unlike the rest of the world in which most plant biotechnology research is financed privately (Huang et al., 2004), Chinese government funds almost all of its plant biotechnology research. In terms of plant-agricultural biotechnology, China is one of the first countries to introduce a commercial GM crop, and has the fourth largest GM crop area, after the US, Canada, and Argentina (Huang *et al*., 2004). Agricultural biotechnology is used as a tool to improve the food security of the nation, increase productivity and raise farmers' incomes. Insect-resistant *Bt* cotton revived cotton production in China and became a successful commercialization project. Now the *Bt* cotton area accounts for about half of the total cotton area in China. MOST has increased plant biotechnology project funding in major research institutes from $8 million in 1986 to $48 million in 1999, and raising this budget by 400% before 2005 (Huang *et al*., 2002). The public-dominated research system sets the agenda for research, in the important national priorities such as *Bt* cotton. Its success with *Bt* cotton demonstrates that plant biotechnology can have a significant impact on agriculture.

Attracting overseas returnees

A 'Talent Strategy' is an important issue to develop biotechnology in China. It is estimated that there are about 300,000 Chinese students overseas now, one-third of them are involved in the biotechnology field (Li *et al*., 2004). These expatriates are becoming as a strong driver for promoting biotechnology in China. Meanwhile, the government also encourages Chinese returnees from overseas to develop their companies with favourable public fund support. Many returnees may be from silicon-valley companies in technology related position. They brought back the advanced technology to set up the start-up biotechnology companies in China. In Shanghai alone, more than 1,700 firms in all sectors have been established by returning professionals. For example, the director of the Beijing Genomics Institute, Dr. Huanming Yang, returned to China after studying and working aboard in a few countries such as Denmark, France and the US (Li *et al*., 2004). In 2009, the Chinese government promulgated a new policy 'Thousands Talent' to attract overseas returnees in high-tech sectors. The policy promises a series of preferential treatment, including a double increase in salaries.

The strategy of attracting talents is generally effective, because China lacks the critical human resources in the biotechnology sector. However, the problem of these programs is that it initially allocated small funding to talents as start-up fund. These funds are generally small and insignificant. When they enter the critical stage of development, there is a problem of the lack of sustained funds, especially when private sector funding is not available or inadequate. Funding constraint still persists as a major bottleneck for these returnees to be able to fully develop their potentials. Again, in human resource development, the state-sponsored model shows a critical role of the state in formulating preferential policies.

Commercializing research organizations

The state sponsored model does not exclude the market. In fact, because reform is market oriented, the state promotes commericialization of research. Besides the establishment of innovation programs, the state plays a strong role in R&D commercialization (Pray, 1999; Keeley, 2003). There are two different routes to commercialization (Keeley, 2003). The first is to set up biotechnology companies based on indigenous technology. The state provides not only research funding but also supportive policies for developing indigenous technology. The 863 program is a very good example for research commercialization through public and private partnership (Keeley, 2003). For example, Biocentury, a firm formed in 1986, was based on the *Bt* gene developed by the Biotechnology Research Institute of the Chinese Academy of Agricultural Science in Beijing. Biocentury's *Bt* gene is already in use in China, where it has earned a majority share of the GM cotton market. The state is the major supporter for the commercialization of the product. The total investment is 100 million Yuan ($12 million) (Keeley, 2003).

The second is to commercialize through managing joint ventures (Keeley, 2003). For example, Monsanto, the largest agricultural biotechnology company in the world, developed joint venture with local seed companies. Monsanto received the most of the profit through expensive technology transfer fee (Keeley, 2003). But the Chinese government has to control MNC because of the risk of depending on foreign technology. The management is through restricting the service area, service sector, venture size and share, and approval procedure. For example, the government restricted the sale of seeds to some provinces in order to preserve local seed firms in other provinces. In this aspect, the government acts more like a developmental state.

Forging high-tech parks

R&D activities are highly concentrated in designated national high-tech parks. In China, these high-tech parks are called 'high- and new technological development zones' (HNTDZs) (*gaoxin jishu kaifaqu*). In total there are 53 national level HNTDZs (Zhouying, 2005).Table 6 shows the distribution of R&D investment by province in China. Investment is concentrated in the coastal region, in the pattern similar to the distribution of GDP performance and the level of economic development. In 2006, R&D investment in Beijing, Jiangsu, Guangdong, Shanghai, Shandong, Zhejiang, Liaoning, Sichuan and Shaanxi exceed 10 billion Yuan (SSB, MOST and MoF, 2007). The overall intensity of R&D investment in China accounts for 1.42% of GDP. Beijing, Shanghai, Tianjin, Shaanxi, Jiangsu, Liaoning, and Zhejiang exceed the national average. In general, the provinces and municipalities on the coastal region are more innovative than those in the central and western region of China, with exception of some major municipalities such as Chengdu, Chongqing and Wuhan.

[Table 6 is about here]

Beijing concentrates the large share of basic research of public research institutes and the top universities, but it lacks a strong industrial base to efficiently commercialize research (OECD, 2007a). Research commercialization has improved dramatically with the development of Zhongguancun Science Park in Beijing. Shanghai has built its strong biotechnology industrial base in the Zhangjiang High-tech Park (ZJHP), based on seven biotechnology research institutions and business. ZJHP is becoming an attractive location for multinational companies to relocate their biotechnology R&D in China. Shenzhen has seen high-tech development with strong entrepreneurship since the early 1980s.

In short, high-tech parks become the sub-national or regional instrument to implement state-sponsored biotechnology innovation model. Measured in biotechnology sector in general, according to Prevezer and Tang (2006), there are three main clusters of biotechnology industry in Beijing, Shanghai and Shenzhen. The Beijing cluster has 177 firms, followed by 160 firms in Shanghai and 126 firms in Shenzhen. Both Beijing and Shanghai have strong bio-science background. In Shenzhen, some successful biotechnology companies emerged. SiBono developed the first gene-therapy medicine in the world. Other reports show that Beijing, Shanghai, Guangzhou, and Changsha as four national biotechnology bases (Liu and An, 2007). It is relatively difficult to identify the exact volume of production and profit in biotechnology because the biotechnology cannot be distinguished from a broader ‘bio-industries’ (*shengwu chanye*) according to China’s statistics. According to the Annual Report on Bio-industry in China, in 2007 there were a number of bio-industrial bases (NDRC-HID, 2007). Table 7 shows the information of some bases.

[Table 7 is about here]

The strength of Beijing is in its high concentration of Science academies and universities. There are Chinese Academy of Science, Chinese Academy of Medical Sciences, Military Medical Science Academy, and China Traditional Medicine Academy, plus four major universities, i.e. Beijing University, Tsinghua University, Beijing Traditional Medical University, China Agriculture University. Beijing has 31.9% of national key labs in medical sciences, and 41% of national key labs of life-sciences. The bio-industrial base in Beijing has its core park in Zhongguancun Life Science Park, Yizhuang’s Beijing ETDZ and Daxing Park. The strength of Shanghai comes from the concentration of research institutions and universities, especially the publications in the top journal such as Nature, Science and Cell, indicate the advantaged stage of life-science research. It has also good production capacities with major pharmaceutical MNCs, many of which locate their China headquarter in Shanghai. Shanghai designated ZJHP as a core park, and extended to Fenglin area of Xuhui District, Qingpu Industrial Park, Nanhui’s

Zhoukang area, and the Spark Park of Fengxian. Guangzhou is a major hub of medical research in southern China. It has plenty of bio resources, especially in oceanic studies. It possesses large domestic pharmaceutical corporations such as Baiyun and Guangzhou Pharmaceuticals. It develops Guangzhou Bio-island and Guangzhou Science Park as the core development area. Generally, the development of sub-national clusters of biotechnology is based on concentration of research institutes, universities and pharmaceutical industries.

The outstanding feature is the development of high-tech or science parks to undertake development activities. Through the state-sponsored program, especially the policy to develop high-tech parks, biotechnology companies present an agglomerated pattern in some key industrial parks. In biotechnology, these clusters include Shanghai's Zhangjiang High-tech Park, Beijing's Zhongguancun Life Science Park and Yizhuang Medicine Park, and Shenzhen High-tech Park.

The development of these high-tech parks are sponsored by local states. The role of municipal governments is critical which can be seen clearly in the case of ZJHP. It has 168 biotechnology companies (including pharma-biotechnology companies) in 2006; its total output value in biotechnology is 4.96 billion yuan (from Zhangjiang High-tech Park website), with 8,580 scientific researchers in 2005 (Zeng and Xiao, 2006). Shanghai municipal government in 1999 adopted a policy called 'Focusing on Zhangjiang' (*jujiao zhangjiang*), giving a series of preferential policies to fiscal arrangement, human resources, project approval, land development, attracting foreign capital and construction of cultural facilities. The purpose of this policy is to concentrate the city's capacity to establish the first-class park. Investment in Zhangjiang mainly came from the government, from Pudong Scientific Development Fund. In 2004, among 87 biotechnology companies under incubation in the Park, 16 companies received special fund. In 2005, 59 new drug development projects received 14.7 million Yuan fund (Zeng and Xiao, 2006). Government venture capital (Zhangjiang High-tech Ltd.) provides additional support.

Because of government sponsorship, biotechnology companies in ZJHP do not form tight functional linkages. Research, development, and industry are still separated in function (Zeng and Xiao, 2006). The connection between companies is not very strong. The linkage between biotechnology companies and pharmaceutical companies has not been naturally developed. The spill-over effect is weak. Prevezer (2008) and Ma & Fan (2008) have reached similar findings about the weak horizontal linkages. The MNCs firms with core technology mainly interact with their headquarters rather than local companies. This is especially the case for CROs. MNCs research labs had limited influence over biotechnology development in the park. However, recent effort is to develop research and industry link. An example is Fudan Zhangjiang, a company developed from Fudan University. Fudan University provides researchers and technology, and the Pudong new district government provides capital to convert research results of Fudan University.

Except these few examples, the link among university, research institutes and pharmaceutical industries is generally weak. This is partially attributed to the state-sponsored R&D model, because the government rather than private venture capital or pharmaceutical companies is the major driver for biotechnology clusters. The research programs are connected with the government funding body in a vertical way rather than horizontally among research institutes and firms. In ZJHP, some research institutes have to find interested partners outside the park to commercialize their research. Simply putting companies and university and research institutes together in the same place would not automatically achieve clustering effects (Zeng and Xiao 2006). The effect of cluster does not just depend on geographic proximity but also the institutional links fostered by innovation policies.

LIMITATION OF STATE-SPONSORED MODEL

Constraint on funding source

Under the state-sponsored R&D model, biotechnology development strongly emphasizes on ‘invention’ and less on the formation of production chain. Technological strength is not equivalent to industrial strength. China needs to fully exploit the use of foreign patents to develop production capacity. Because of the risk in drug development, it is difficult to attract venture capital with proof technology. In 2002, venture capital only invested US$ 420,000 in biotechnology in Shanghai, only accounting for 10% of the total venture capital (SJU, 2006). The burst of the stock market in 2001 reduced the source of investment. Investment in biotechnology pharmaceutical declined, as venture capital hesitates to invest. Recently, the price of medicine declined, while the costs of consumables increased. From 2002, about 1,080 enterprises attracted $5 billion from the stock market. But biotechnology only accounts for 5.2%. Only one product (Shenzhen Watsin Genetech Co's rhEGF) was developed through venture capital. Access to finance is a major bottleneck for biotechnology companies (Hu, 2007).

Globally, biotechnology industry is characterized by dominantly large companies. The total output value of Chinese biotech companies is below the sales of Amgen. There are too many small enterprises in China. China lacks flagship biotech companies such as Genentech and Amgen in the US. For example, for INF product, there are more than 20 companies with a capacity of 400 million bottles. The actual production in 2004 was 50 million bottles with sales value of 1.2 billion Yuan. The product in the US was sold by a single company with sales of $1.8 billion. But the market potential of this product in China is huge, as China has 20 to 30 million Hepatitis B and C patients. The market share captured by the company allows the return of their R&D investment through high drug price control. This is why R&D can be maintained at a higher level in enterprises.

The constraint on funding sources is evident in science parks such as Zhangjiang High-tech Park. Figure 5 shows the funding composition, which shows that the proportion of venture capital is quite limited. The funding source is heavily skewed towards the central and local governments.

[Figure 5 is about here]

The state sponsored model does not fully utilize China's comparative advantage of labour cost. It does not help to develop China's human resource potential. While the low cost and highly skilled scientists add strength to biotechnology development, China still does not have enough experienced experts in its 'talent' pool (Yu, 2007), because the development of biotechnology requires experienced researchers 'who are visionaries with diverse talents, and who are capable of soliciting venture investment, steering research directions, and evaluating research programs' (*ibid*). However, various programs to attract overseas Chinese returnees help to strengthen its talent pool. The state sponsored approach may help to create a pool of scientists but not entrepreneurs with scientific knowledge. The program needs to be more industrial oriented.

Under-performed IP-protected output

Patent statistics provide a measure of innovation output. According to OECD (2006b), in 2004, the US had the highest number of biotechnology patents (patent application filed under Patent Cooperation Treaty (PCT)), accounting for 39% of the world total, while Japan and Germany are at the second and third position, accounting for 18% and 10% respectively (Figure 6). In terms of the number of patents, China only has 1.4% of the total. However, the applications for biotechnology patents to EPO (European Patent Office) increased remarkably in China, reaching the highest rate of 50% in the period from 1995 to 2003, while the US only increased by 2.4% in the same period.

[Figure 6 is about here]

Moreover, compared with the US and Japan, China saw a higher proportion of biotechnology inventions owned by foreign companies or co-inventors (Figure 7). The foreign ownership in Japan is less than 10%, and in the US the figure is about 12%. The same figure for China is as high as 50% (OECD, 2007b). This indicates that, on the one hand, China's biotechnology development is very much internationalized; on the other, China still lacks its indigenous R&D capacity in biotechnology sector. Despite government funding, about half of inventions in biotechnology is owned by foreign partners. This means that government input has not led to the scale of patented products. Investment is more in basic research rather than forming a capacity of innovation. Because the state is the major sponsor in R&D in China as indicated in Figure 3, the enterprise received 60% of government funding, but the funding was mainly invested in importing technology rather than developing technology. In the current funding environment, a great portion of the funding has been diverted to building the physical infrastructures rather than supporting research, which results in limited invention. In contrast to government funding, the multinationals are more efficient in development of new technology, especially in applied research using China's advantage of strong science pool and cheaper labour cost. The low patent ratio also shows the limitation of state sponsored model in terms of knowledge generation which can be used to capture added value in production.

[Figure 7 is about here]

Although a few international biopharmaceutical companies come to China, many have not made substantial investment. Intellectual property rights (IPR) protection regulation is considered as one of big barriers to foreign investment to achieve the 'win-win' strategy. IPR plays a critical role in the survival of the biotechnology industry and in providing incentives for firms to invest in R&D (Loppacher and Kerr, 2004). Since joined in World Trade Organization (WTO) in 2001, China has committed to improve its IPR protection regulation.

EVOVLING MODEL AND COMPARISON

Evolving model of biotechnology development

China's state-sponsored R&D in biotechnology is not a static model. It adapts according to challenge and constraint. Because China has developed a rather active R&D market environment, faced with funding constraints, biotechnology firms began to seek funding outside the state source. One route is to play the relative strength of low labour cost. The cost of research scientists was estimated to be 5-10 times lower than in the US. Given relatively low cost of skilled researchers, available equipments and consumables and large patient population for expensive clinical trials, international biopharmaceutical companies began to use China as the basis for laboratory work. There is a wide range of opportunities for biotechnology services in China. Therefore China may become the 'global laboratory' for biotechnology development, built upon its experience of evolving into the world factory. There are recently three new changes in the biotechnology model.

First, Chinese research institutes began to collaborate with foreign pharmaceutical companies for in-licensing drug development. Chinese biotechnology companies are active in in-licensing drug compound discovery. They developed candidate compound in preclinical and clinical development. The technology focuses on gene therapy, antibodies and traditional Chinese medicine (TCM) modernization. TCM modernization including high-throughput screening and other techniques aimed at the discovery of active compounds offers China a competitive advantage in drug discovery.

Collaboration between foreign pharmaceutical companies and Chinese biotechnology appears to be an important development. For example, Paris-based drug discovery company Hybrigenics signed a joint research project with Shanghai Institute of Material Medical to screen candidate compounds made in the Institute (Jia, 2005). Based on large patient population, foreign companies can outsource the costing clinical trials to Chinese biotechnology companies. For example, US biotech Cephalon signed a deal with CRO (contract research organization) in Beijing Med-Pharma for clinical development of its cancer painkiller Fentora in China (Jia, 2007). More multinationals have established research centres in China. These include Pfizer Pharmaceuticals in Beijing, GlaxoSmithKline in Beijing, Novartis Pharmaceutical in Beijing and Merck in Shanghai (Li *et al*., 2004). Moreover, Roche and Eli Lilly have opened R&D centres in China too. Although this might not bring in technology, it at least injects needed resource into biotechnology. Many firms developed collaborations with Chinese healthcare biotechnology enterprises through joint ventures. Also, through working in these joint ventures, Chinese bio-scientists began to develop some experience in biotech entrepreneurial skills which may be useful for the human resource development.

Second, merger and acquisition is another strategy in global biotechnology. China biotechnology enterprises provide manually intensive but high skilled bio-services to biotech and pharmaceutical companies internationally and may find an exit through acquisition. The bio-services include nucleotide sequencing and synthesis, protein expression and library construction (Chervenak, 2005). For example, Beijing Genomics Institute (BGI) now provides genome sequencing services worldwide. Chinese companies provide lower-end bio-equipment, reagents, and consumables services. Some suppliers began to move into high-tech equipments and analytical software. In 2004, Invitrogen Corp., the world biotechnology product and service giant, acquired BioAsia Co., a Shanghai-based bio-services provider, in order to expand its China presence both in terms of distribution and to augment its service capabilities (Chevenak, 2005). The successful acquisition showed an optional exit for biotechnology enterprise in China.

Third, China provides a manufacturing base for global firms. The government has approved more than 20 biopharmaceuticals and have granted more than 130 companies with good manufacturing practice certification (Chevenak, 2005). The biopharmaceutical market is primarily generic and most domestic players have to compete on price for the same product. These biopharmaceutical companies show excess manufacturing capacity. With excess capacity and competitive price market, many Chinese biopharmaceutical manufacturers can be good candidates for partnership or acquisition with international biopharmaceutical companies. For example, Dragon Pharmaceuticals Inc. of Canada and GeneMedix Plc. of the United Kingdom have already established a manufacturing base in China. However, the regulation of importing biotech drugs in the European and US markets is strict, and thus developing an export-oriented biopharmaceutical manufacturing business model would be more difficult. This indicated China cannot solely emulate its successful export-oriental model in textile and electronics into biotech industry (Jia, 2007).

Comparison of different innovation models

Comparing the growth of biotechnology industry in the US, UK and China, we can see the different innovation models. Table 8 provides an initial factual comparison and Table 8 further compare Chinese model with the typology of three basic approaches of innovation. Because the US and UK models share some similarities, in discussion we focus on the comparison of US and China.

[Table 8 is about here]

In the US, biotechnology companies are usually founded on a specific technology, discovered or invented in research. Through convincing and attracting venture capital, the aim is to convert the invention into a commercial product. This moves the technology into clinical trial, which requires large funding. This stage is critical to the survival of biotechnology companies. Some biotechnology companies are successfully purchased by big pharmaceutical companies and moving into the manufacturing and marketing stage, while a large number did not make it through this stage and demised. The mature stock market and available debt financing from bank make the US to be dominate player in the global biotechnology industry.

In China, biotechnology started from research outputs of universities and research institutes, or technology brought back by overseas returnees. Some inventions are imported bought or counted as technological share in the company. The initial funding is from government research programs; for start-ups, special incubation funding is available. The government encourages spinning-off. When technology is tested, approval and IP are sorted out. The technology moves to the manufacturing stage but there are few buying-out, owing to the limited capacity of domestic pharmaceutical companies. For foreign manufacturing buying out, IP in overseas should be sorted out but this is often difficult. There is very limited exit to attract the private investors. Stock market just started in China and most of investors are only interested in low-risk and short-term return sector rather than biotech sector with high-risk and long-term commitment. Debt financing is impossible in China. The lack of funding plus a new round of globalization in R&D forces the Chinese biotech sector as a whole to use the revenue generated by providing out-sourcing services to foreign biopharmaceutical companies.

Table 9 further compares the Chinese biotechnology innovation model with the typology of three approaches in innovation. Compared with the entrepreneurial model, the Chinese version has seen significant degrees of marketization of the economic system. But the intervention of the state is much stronger. Similar to a flexible labour market, China aims to attract overseas talent through higher salaries and shared rewards. In terms of private ownership and subcontracting, China began to see emerging private biotech companies and CROs which are driven by market signals. However, in other aspects, the Chinese version deviates from a liberal market model. The degree of state intervention is high, and the state actively formulates long-term S&T plan. This is similar to the developmental state model, which uses the ‘plan rationality’. Different from the liberal market model, the state sponsored major funding programs. Compared with the partnership model, the Chinese market is less regulated and does not see much influence from business associations. However, the local state plays an active role in developing high-tech parks, by providing land, funding and infrastructure development. Different from a risk sharing and trust based partnership model, the Chinese model does not see a sustained and strong business linkage between banks and firms, horizontal link between industries, and link between university and industry. Compared with the developmental state model, China shares similarity in terms of the level of state intervention. However, the banks are less risk taking in the capital market and do not provide sufficient support for biotech. Rather, the state-sponsored funding becomes a major source. Moreover, the Chinese state-sponsored model does not see the dominance of public ownership. Instead, in biotech R&D, CROs become active, wholly depending upon the market.

In sum, the Chinese model is a hybrid one – better known as a state sponsored model rather than a classic developmental state one. The role of the state and dominance of state funding resemble to the developmental state model. However, China has also seen an aggressive marketization process. The state also encourages labour mobility. Private biotechnology companies are emerging, and new CROs developed quickly. In relation to the partnership model, there is no strong business or local commercial organization. But the local state plays a very significant role in high-tech park development. In general, the link between research and industry is weak, because of the legacy of state dominance (Prevezer, 2008; Ma & Fan, 2008).

[Table 9 is about here]

Given the decentralisation of governance in China, we pay special attention to the regional level to see how a decentralized innovation system operates in localities. By 'region', we follow the definition by Cooke (2001), which is referred to as 'a meso-level political unit set between the national or federal and local levels of government that might have some cultural or historical homogeneity but which at least have some statutory powers to intervene and support economic development, particularly in innovation'. We illustrate our observations in the Chinese case through three biotech clusters in China.

Shenzhen was established as a ‘Special Economic Zone’ by the central government in early 1980s and grew rapidly as a centre for manufacturing for export in Pearl River Delta region. With the favourable policies, risk-taking entrepreneurship, flexible low-cost labour market, Shenzhen was attractive as a platform to overseas returnees in early 1990s due to its flexible regulation (Chen & Kenney, 2007). The advanced technologies were brought back by returnees from aboard, especially from USA. The favourable policies have attracted large number of overseas talents to set up high tech companies in Shenzhen through higher salaries, incentive tax and share reward. The initiative of Shenzhen as special economic zone and establishment of Shenzhen University suggest strong state-sponsored innovation model. Meanwhile, technology commercialisation in Shenzhen is more market-oriented. For example, Shenzhen manages to commercialize some technologies developed by Shanghai-based biotech companies. The local government recognised the lack of major universities in Shenzhen and proposed a policy to attract top universities and research institutes to set up their campus in Shenzhen. It proved to be an effective shortcut to overcome the shortage. Now, technology flows in Shenzhen are not only from aboard, but also from other cities such as Beijing and Shanghai.

Shanghai strategically focuses on Zhangjiang as its biotech base. Shanghai municipal government designates biotechnology in ZJHP as one of the new industrial sector of Shanghai. The government managed to relocate the Chinese Human Genome Centre from Beijing and Chinese Medical University and its affiliated hospital from Shanghai Puxi to Pudong, which clearly reflects a model of strong state intervention (Prevezer, 2008). By 2007, there are more than thirty research institutions, ten foreign-owned R&D centres (e.g. Roche) and about 265 small-to-medium size local biotech companies in ZJHP. Because of the strategy, Shanghai has become the first location for most of multinational pharmaceutical or biotech companies to set up R&D centre in China, while Beijing is more attractive for regional headquarters of multinational companies. Nevertheless, the state sponsored model has its limitation, as discussed earlier. Biotech firms cannot receive sustained investment. Many have to shift to contracted research for foreign firms, taking the advantage of low cost and huge patient population in China. The emergence of CROs suggests that biotech companies are driven by market signals rather than a wholly plan rationality. Recognized the need for finance, in 2006, the Shanghai Pudong New Area Venture Fund with $125 was established as the first policy-directed venture fund supported the local government to support start-ups. The fund aimed to attract $2.5 billion venture capital (ZJHP, 2007). This is similar to European partnership model to share the risk for high-tech investment between public and private. But the market in China is less regulated than that in Europe where partnership model is associated with rule-bound and legalistic regulation of economic activity.

Beijing benefits from strong science base, rich human resources from top universities, the capital and central government. But in biotech there was little manufacture industry and relative weak commercial tradition. After the S&T reform in 1985, technology enterprises known as *mingying keji qiye* were created. Most of them were spin-offs from the enterprises. Chen & Kennedy (2007) suggest that there was a historic linkage between these spin-offs and research institutes. However, the research technology commercialisation is generally weak, not like USA. These privatised high-tech companies are usually run by a group of scientists from universities or research institutes. They are good at research technology, but lack entrepreneurship and management skill. Biotechnology commercialisation usually requires wide ranges of talents with different skills including scientific, clinical, financial, legal, marketing, manufacturing, and management.

To sum up, there are several advantages and disadvantages for Chinese biotechnology: the strategic push from the government with a clearly defined vision to set biotechnology as one of the frontier areas is an advantage. The environment for biotechnology start-ups is good, given that initial funding support and low-cost researchers are available (but the funding is not up to what is needed to commercialize the product; and the experienced researchers with entrepreneurial skills are lacking). The main disadvantage is that China lacks a mature pharmaceutical industry to support biotechnology commercialization. It is difficult for biotechnology companies to find later-stage funding sources, and the support from industry and venture capital is too thin. Enterprise investment in R&D is too limited. For example, biotechnology companies in Shanghai's Pudong only account 41 million Yuan in 2003, accounting for 3% of the sale in the year, far lower than 45% investment in R&D in the US since 1994 (SJU, 2006).

Biotechnology in China is still in its very initial stage, though the capacity of research is under formation. This means that the state needs to continue to sponsor start-ups. However, it should be clearly understood that access to finance needs to go beyond government sponsorship. The domestic market for biotechnology is under-developed at the moment, partially because of immature pharmaceutical industry. This may also reflect ultimately the affordability for expensive new drugs developed through biotechnology. Expansion toward the overseas market still faces much complicated and tougher IPR and approval procedure.

CONCLUSION

This paper examines the model of China's biotechnology innovation. We applied the theoretical typology, namely three models of innovation, to the Chinese case. We demonstrate that the development of biotechnology in China is driven by the state-sponsored R&D programs. This innovation model was necessary at the earlier stage of biotechnology development, because it built upon the strength of state-funded research institutions and universities. China has the record of agricultural biotechnology (e.g. *Bt* cotton) and some healthcare biotechnology (e.g. insulin). This approach laid down necessary infrastructure and stimulated the clustering of biotechnology firms in select high-tech parks. But the Chinese model mixes up several elements in the theoretical models. Especially, it resorts to the market-oriented approach to R&D, despite strong state control and funding. A significant feature of this model is the role of local state in the development of high-tech parks. At the sub-national level, high-tech parks are regional innovation systems which combine various local advantages to form an agglomerated pattern of biotechnology development. The local state often uses land development mechanism to develop infrastructure and attract biotechnology and pharmaceuticals. This is somewhat resemblance to a partnership model, which suggests the importance of institution advantage in these high-tech parks.

However, such a state-sponsored approach has its limitations. The major problem is the lack of sustained investment. Although China has generated a huge surplus of capital, the private venture capital is under-developed. In the period of economic boom, there was a strong pressure to reinvest capital, but a significant amount was diverted into the real estate and stock market. The mechanism for private investment in high-tech has not been fully established. Related is the issue of IPR. Also the state funds significantly in R&D, a large proportion is used in importing technology licensing rather than investing in R&D. China now needs to build upon its strength of state-sponsorship but has to realize that the nature of biotechnology sector requires sustained long-term funding. It is not possible for the state alone to bear the funding responsibility.

Faced with funding constraint and an actively market-oriented political economic environment, Chinese firms began to seek alternative models. A major departure from state sponsored R&D is the fast growth of CROs, building upon China's comparative advantage of low labour and operational costs. Thus, China's biotechnology innovation model is not a static one; it evolves with new opportunities and challenges.

Acknowledgement: The funding support from Leverhulme Trust (F/00 407/AM) is acknowledged. Usual disclaimers apply.

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Table 1. Investment in R&D in the world

Country	GDP PPP* (billion USD) (2005)	Percentage of R&D in GDP (2005)	R&D PPP (billion USD) (2005)	R&D PPP (billion USD) (2006)	R&D PPP (billion USD) (2007)
China	8,859.0	1.4	124.03	136.30	149.80
US	12,192.6	2.6	319.60	328.90	335.50
Japan	3,890.0	3.2	124.48	127.84	131.29
Germany	2,388.6	2.5	59.68	60.21	60.75
UK	1,933.3	1.9	36.72	37.39	38.06
France	1,879.9	2.2	41.36	42.10	42.86
Canada	1,033.9	2.0	20.66	21.26	21.88
Sweden	283.5	3.9	11.04	11.33	11.64
Israel	154.5	4.5	6.95	7.31	7.69
Singapore	124.3	2.2	2.73	2.91	3.10
World	50,002.0	2.0	978.34	1015.46	1051.75

Source: Duga and Studt, 2006; OECD, 2007a.

Note: PPP: purchasing power parity. GDP: growth domestic product.

Table 2. Key indicators of biotechnology companies in the world in 2004

Country	Companies [a]	Employees	R&D employees	R&D spend (billion USD)	Revenue (billion USD)
China	~500	50,000	30,000	1.80 [b]	2.40
USA	1,991	190,462	79,344	28.36	56.18
UK	457	21,134	9,384	2.11	6.12
Germany	538	16,094	8,132	2.04	3.94
France	223	9,142	4,246	0.80	2.97
Sweden	138	3,942	2,579	0.50	1.16

Source: Chong, 2005; CNCBD, 2007; EuropaBio, 2006, exchange rate at 31 Dec., 2004, $=0.739€.

Note:

a. The definition of biotechnology company is referred to EuropaBio, 2006. Big pharma companies, other major corporate and companies for whom biotechnology is an important but, nonetheless, minor part of their business, are not included in the above table. However, those may be included in other studies as biotech companies. The statistics figures about biotech may be varied depending on the data resources.

b. The figure about China’s R&D spending is total cost during 2000-2005.

Table 3. R&D programs launched by the Chinese government.

Program	Year	objective	Total funding (Billion RMB)
Key technologies	1983	Promote the development of key technologies need for industrial and social development	1,498
"863"	1986	Promote R&D capabilities in high tech	929
Torch	1988	Commercialization of new technologies, entrepreneurship through incubators and science parks	2,899
	2004		7,131
Spark	1986	Diffusion and adoption of technologies in rural China	1,475
	2004		2,057
National Key Laboratories	1984	Basic and applied research	95
National Natural Science Foundation	1986	Basic and applied research	100
Climbing	1992	Basic research	17
"973"	1997	Support basic research in selected areas	103
"985"	1998	Support key research universities	n.a.

Source: Hu and Jefferson, 2004; OECD, 2007a

Table 4. Strategic areas of biotechnology specified by the Medium- and Long-term Science and Technology Development Plan.

Drug target discovery	Functional characterization of key and disease-related genes: drug target screening and validation.
Animal and plant models and drug design	Analysis and integration of bio-information; drug design and metabolism; computer-assisted designs, syntheses, and screening of compound libraries based on combinatory chemistry.
Gene manipulation and protein engineering	Chromosome structure and site-directed integration; design and manipulation of protein-coding genes; polypeptide chain modification; structure solving; scaled protein purification.
Stem cell-based human tissue engineering	Therapeutic cloning, directional differentiation; *in vitro* construction of structural organs and production; construction and damage repair of complex organs with multiple cell types.
New generational industrial biotechnology	Scaled screening of functional microbes; modification of bio-catalysts and industrial production; bio-conversion media and systems for industrial operation.

Source: compiled from Yu, 2007.

Table 5 Budget of "863" programme and the share of biotechnology programs.

Year	Total Budget (million USD)	Share of biotechnology program
1987-2000	712.5	26%
2001	206.25	27%
2002	537.5	33%
2003	384.4	26.8%
2004	468.75	22.6%
2005	511.9	18.5%

Source: Liu and An, 2007.

Table 6. Regional distribution of R&D investment in China in 2006

Area	R&D spend (billion RMB)	R&D% GDP
China	300.31	1.42
Beijing	43.30	5.50
Tianjin	9.52	2.18
Hebei	7.67	0.66
Shanxi	3.63	0.76
Inner Mongolia	1.65	0.34
Liaoning	13.58	1.47
Jilin	4.09	0.96
Heilongjiang	5.70	0.92
Shanghai	25.88	2.50
Jiangsu	34.61	1.60
Zhejiang	22.40	1.42
Anhui	5.93	0.97
Fujian	6.74	0.89
Jiangxi	3.78	0.81
Shandong	23.41	1.06
Henan	7.98	0.64
Hubei	9.44	1.25
Hunan	5.36	0.71
Guangdong	31.30	1.19
Guangxi	1.82	0.38
Hainan	0.21	0.20
Chongqing	3.69	1.06
Sichuan	10.78	1.25
Guizhou	1.45	0.64
Yunnan	2.09	0.52
Tibet	0.05	0.17
Shaanxi	10.14	2.24
Gansu	2.40	1.05
Qinghai	0.33	0.52
Ningxia	0.50	0.70
Xinjiang	0.85	0.28

Source: SSB, MOST and MoF, 2007.

Table 7. Information about some 'bio-industrial bases' in China (data from January – October 2007)

Bio-industrial base	Production value (billion yuan)	Profit (billion yuan)
Beijing	19.2	2.8
Shanghai	29.3	2.7
Guangzhou	22.5	4.7
Shenzhen	26.6	2.3
Changsha	24.2	2.6
Chengdu	35.1	3.7

Source: NDRC-HID (2007)

Table 8. Comparison of biotechnology in the US, UK and China

Country	US	UK	China
Finance	NIH funding Business angels Venture capital (VC), Stock market Debt financing	Business angels; VC; Stock market	Government funding; Government supported venture capital
R&D investment (billions, USD)	28.36 (in the year of 2004)	2.11 (in the year of 2004)	1.8 (total from 2000 to 2005)
Sale volume (billion USD)	56.18	6.12	2.4
R&D management	NIH; NSF; Foundation	BBSRC; DTI; Wellcome Trust	MOST; NSFC
Performing R&D	Universities; Research institutes; and Enterprises	Universities; Enterprises; and a few research institutes	Universities; Research institutes, and enterprises,
R&D collaboration	Very strong co-research; co-patenting; and co-publishing	Co-research; co-patenting, and co-publishing	Inactive link for technology transfer between universities and enterprises.
Size of enterprises	Dominated by a few big biotech such as Amgen and Genentech etc.	SMEs	Relatively concentrated in some biotech firms such as Biocentury, Sinov, Sunway
R&D environment	Universities; many clusters; and bio-science parks	University; clusters and few bio-science parks	Universities; Shanghai biotechnology cluster
Vision	Keep as global biotech No. 1 player	Keep No. 1 player in EU	Top 5th player in 2020
Strength	Flexible finance system, entrepreneurship,	Strong science base; regional government support,	Government support; lower cost of the skilled labours
Limitation	Volatility of finance market;	Moderate entrepreneurship culture; lack of big pharmaceuticals;	Undeveloped finance system; Lack of manager talents; Unregulated IP protection

Table 9. China's biotechnology innovation model with reference to the theoretical typology

Model	Theoretical description	Chinese observation
The entrepreneurial model	- Dominance of liberal market, - flexible labour market, - private ownership, - outsourcing and subcontracting	- significant marketization of the economic system but under state direction, - attracting talent through higher salaries and share rewards, - emerging private biotech companies - contracted research organizations (CROs)
The partnership model	- regulated market, - business association and chamber of commerce, - risk sharing, - cooperation between universities and public research institutes	- less regulated market, - a significant role of the (local) state in developing high-tech parks, - weak link between university and industry and horizontal link between industries
The developmental state model	- planning rationale, - state bank support and greater state influence in the capital market, - state controlled ownership	- involvement of the state in strategy formulation (e.g. long-term S&T plan) - dominance of state funding and S&T programs, - public ownership is not dominant

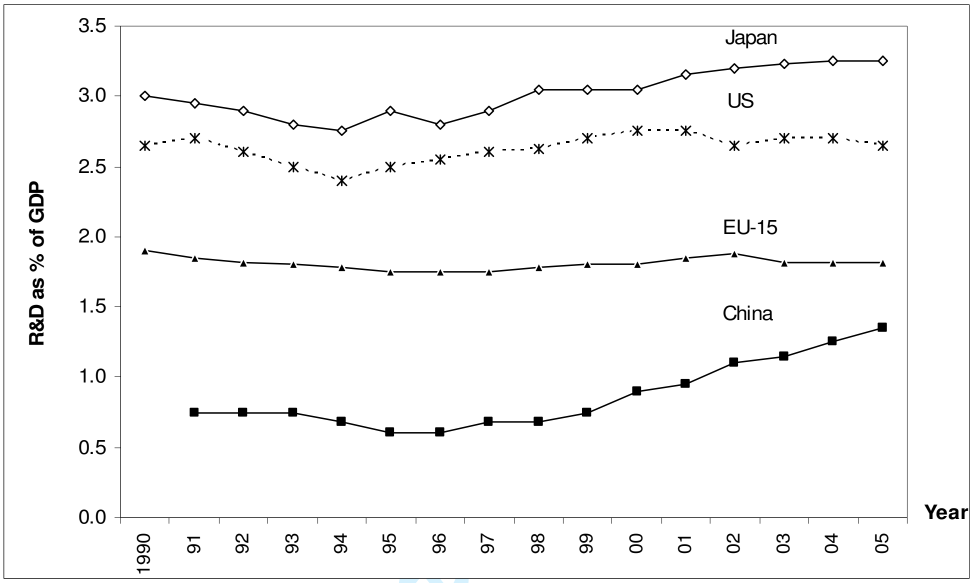

Figure 1. The growth of R&D intensity as the ratio of R&D investment to GDP in China during1990-2005.

Source: Doug and Studt, 2006; OECD, 2007a

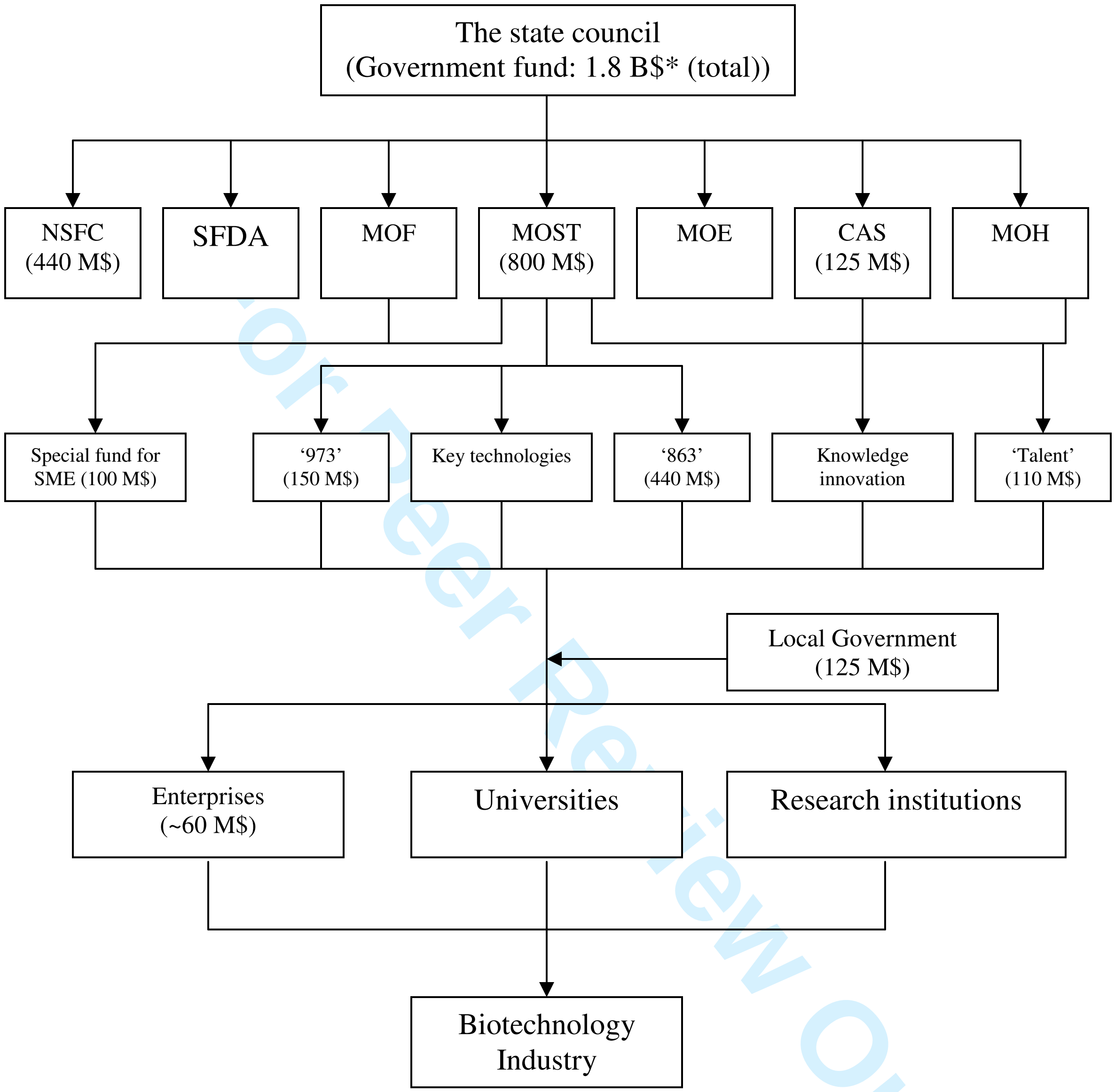

Figure 2 Biotechnology R&D management system in China.

Source: modified from CNCBD, 2007.

Note:
MOST: Ministry of Science and technology
SFDA: State Food and Drug Administration
MOE: Ministry of Education
NSFC: National Natural Science Foundation of China
MOH: Ministry of Human Resources
CAS: Chinese Academy of Sciences
* indicates the total investment on biotechnology.

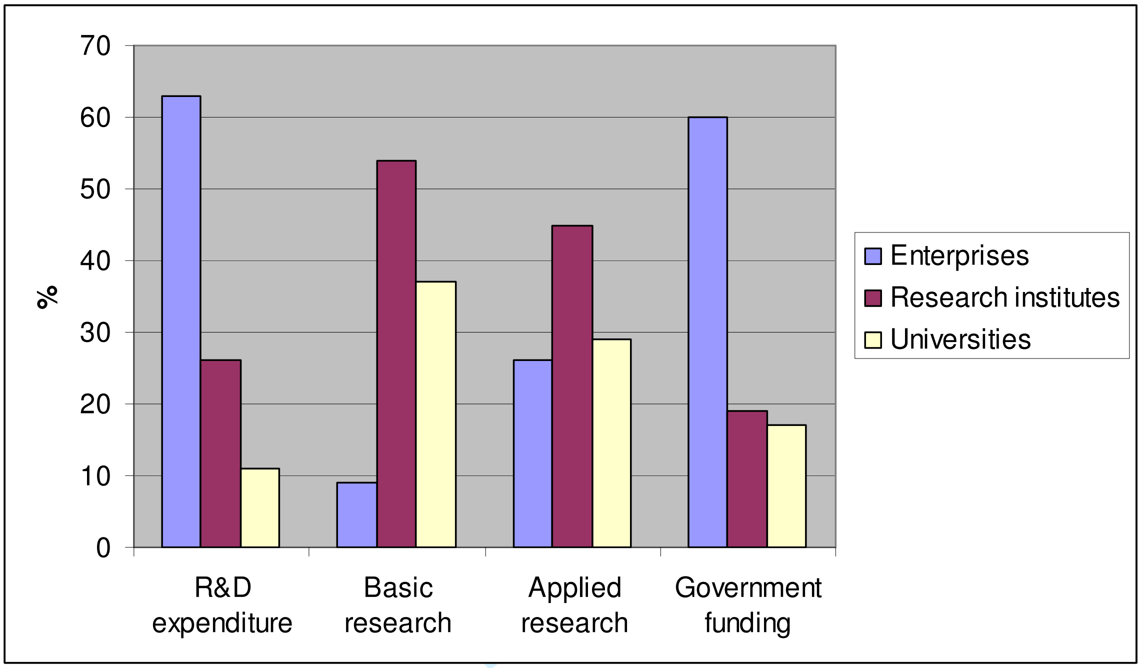

Figure 3. The funding of three main performers of R&D in 2003
Source: OECD, 2007a.

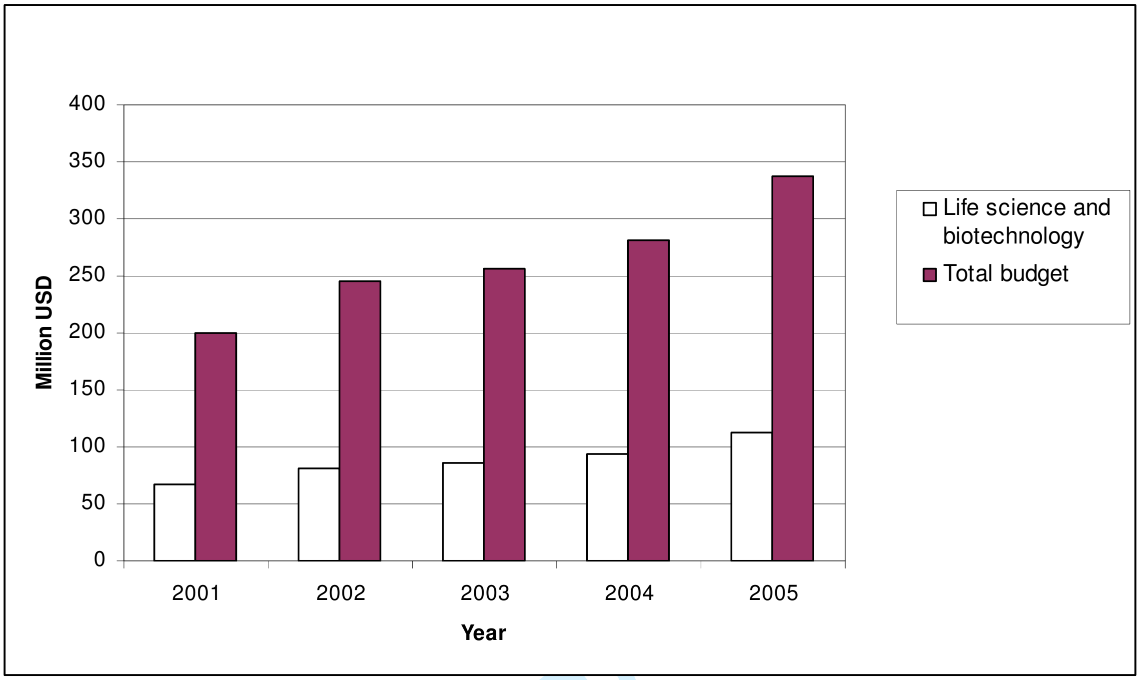

Figure 4. The life science and biotechnology funding in National Natural Science Foundation (NSFC) from 2001 to 2005.
Source: compiled from Liu and An, 2007.

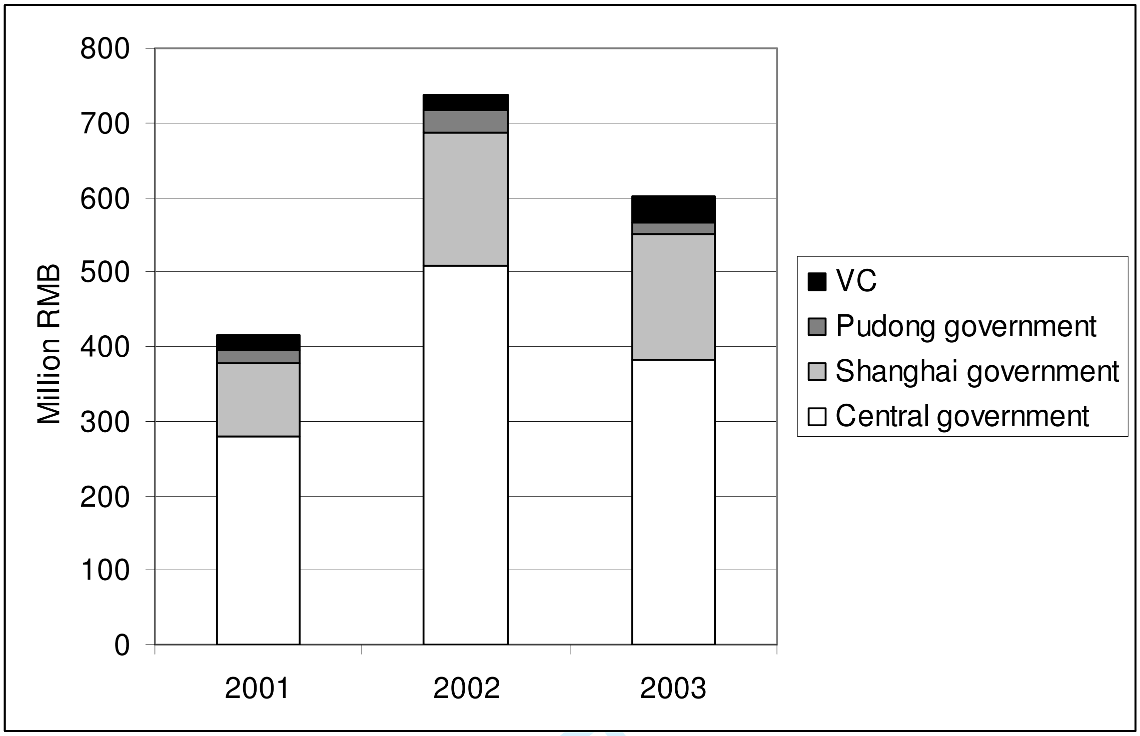

Figure 5. The composition of funding source in Zhangjiang Biotech cluster
Source: compiled from Monitor Group 2005

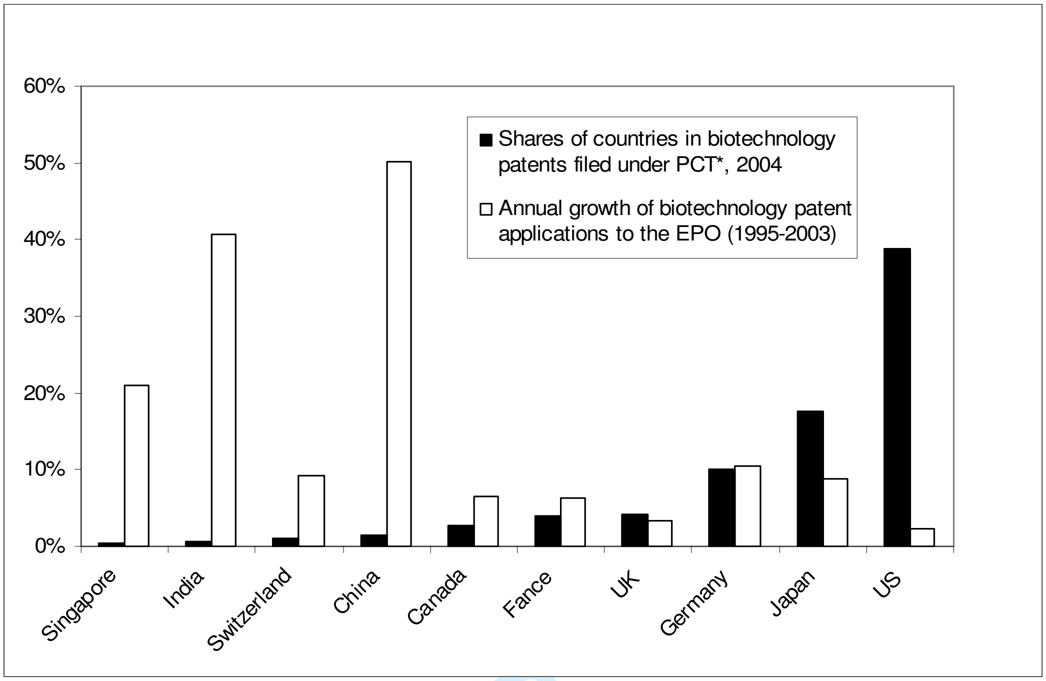

Figure 6. The share and growth of global biotechnology patents.

Source: OECD, 2007b

*Note: PCT: Patent Cooperation Treaty; EPO: European Patent Office

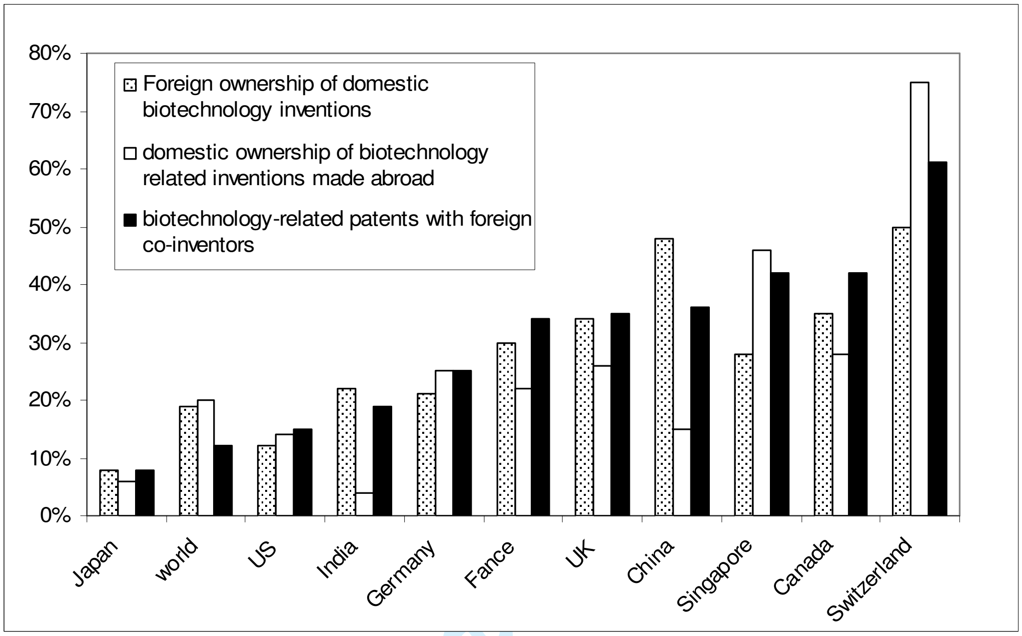

Figure 7. Internationalization of biotechnology related inventions of selected countries, 2001-2003.

Source: OECD, 2007b