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**A romance of the three kingdoms
and the tale of two cities:
the role and position of the
biotechnology industry cluster
in Guangdong province, China**

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Abstract

The Guangdong Province has been at the forefront of export-based economic development in China. Due to rising labor and environmental costs continuing in this path is becoming unsustainable. Guangdong embarked on a two-prong strategy: (1) relocate low cost manufacturing from coastal regions inland and (2) upgrade the industrial structure in the coastal Pearl River Delta by developing clusters for innovating activities in high-tech fields such as biotechnology (BT). BT activities in Guangdong are clustered in and around the capital Guangzhou and the new industrial city Shenzhen.

The paper aims at answering the following questions: (1) How does the Guangdong BT cluster compare with the two better known ones in Beijing and Shanghai? Does the BT science and academic infrastructure in Guangdong create conditions for a sustained innovation-based growth of BT industry? (2) Does the emergence and evolution of the two Guangdong bio-regions in Guangzhou and Shenzhen conform to Orsenigo's theoretical hypothesis that "innovation generates clusters at least as clusters create innovation"? (3) How does the government controlled and supported emergence and evolution of Chinese BT clusters compare with the theoretical interpretation of clustering in the West. (4) Is high-tech biotechnology in Guangdong becoming one of the significant high-tech/high value-added alternatives to traditional labor-intensive export industries? To respond these questions we rely on Chinese official statistics and other sources complemented by findings of the survey of about fifty BT firms and research institutes in Guangdong province.

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1. Introduction

Since the beginning of economic reform in late seventies, the Guangdong Pearl River Delta area has been an “experimental region” for China’s economic reform. Based on the orientation toward a market economy, Guangdong province is the Chinese province that has formed the most complete market system. One of the advantages that contributed to Guangdong’s transformation to market economy is its proximity to Hong Kong.

Based on the last forty year’s exercise of “open economy”, Guangdong province has transformed from a province based mainly on agriculture and traditional labor intensive industries into the largest provincial economy in China and the manufacturing shop-floor of the world. The population of the province is approaching 100 million and the average GDP per capita is 7000 US\$, much higher than China’s average level of 4 283 US\$. The per capita GDP in Pearl River Delta, the industrial export oriented core of the province and of China, is about 10 000 US\$, more than ten percent higher than the world average.

Among the key factors of Guangdong’s economic success are the highly specialized production clusters in various labor-intensive manufacturing industries. The particularity of GP’s clusters is that a village, city or county are often specialized in producing a particular category of a product, such as women’s apparel in Shenzhen, Man’s costume in Shanwei, Children’s apparel in Foshan, etc. The companies are typically small or medium size and compete fiercely with each other.

Although Guangdong’s GDP still ranks first among 31 provinces, its lead relative to other provinces is declining. According to the Chinese Academy of Social Sciences, in terms of overall competitiveness Guangdong is now in the fourth place behind Shanghai, Beijing and Jiangsu.¹ The principal reason for the declining competitiveness is the relatively low value-added of Guangdong’s manufacturing industries. After 40 years’ of development,

¹ « Report on Forecast of China’s Provincial Economic Comprehensive Competitiveness », various issues since 2005. Chinese Academy of Social Science (CASS).

the industry remains still specialized in labor-intensive low value added traditional sectors, such as furniture, leather products, apparel and in assembly of electronic products and computer & communication equipment. In the last ten years, the GDP created by one new employment in Guangdong was only 120 000 Yuan, much lower than the 880 000 Yuan of Jiangsu, 250 000 Yuan of Zhejiang or 220 000 Yuan of Shandong (Sun and Shi , 2011).

The growing environmental problems, energy shortages, rising labor costs and unrests show that further expansion of the labor-intensive export oriented industrialization is not sustainable (Yongda Yu and Hao Wang, 2010; Arvanitis, 2006). Facing this reality, Guangdong province adopted a “double transfer” strategy, which aims at: (1) transfer the low value-added traditional manufacturing sectors to the relatively less developed inland cities, and (2) foster the development of High-Tech & High Value-added industries and services.

This paper deals with the second strategy, focusing on one of the prioritized high-tech, high-value-added industries, the development of industrial applications of modern biotechnology. Biotechnology industry has been defined as a “collection of firms that focus on the application of recombinant DNA and the related technologies” (Feldman, 2003). The development of BT is targeted by many nations as one of the new industries with the highest potential and likely source of new technological revolution in the twenty-first century (OECD, 2006). It is used in agriculture, environmental technology, renewable energy, manufacturing and, above all, in health related applications such as manufacturing of medicines by biological rather than chemical processes and also in some medical equipment and devices.

Given China’s successful policy of export oriented industrialization by means of top-down government-promoted production clusters, it is not surprising that analogical policies are used to build clusters in biotechnology and other high-tech industries. Successful innovation clusters in high technology fields such as ICT or biotechnology stem from a “constructed” advantage, i.e. scientific and technological institutions connected to related manufacturing firms and business services by formal and informal social interactions within and outside the cluster, generating innovation-based growth, as exemplified

by Silicon Valley. This suggests that replication of cluster policies that were successful in developing labor-intensive export industries is unlikely to be as successful in biotechnology which requires scientific research infrastructure with highly qualified manpower. The key and most elusive characteristics of successful innovation clusters, the creative buzz generated by social interactions, is the most difficult-one to build.

Previous research has identified three provinces with agglomeration of biotechnology research and industry: Beijing, Shanghai and Guangdong Province (Prevezer and Tang, 2006; Zhang et al. 2011). In contrast to the better documented biotechnology activities in Beijing and Shanghai there is less information on the situation in Guangdong Province. Is there a single cluster in and around the new city of Shenzhen as reported by Prevezer and Tang (2006) or in the provincial capital Guangzhou as suggested by Zhang et al. 2011)?²

This study addresses three principal questions:

- (1) How has Guangdong's structure and performance of biotechnology research and production evolved in comparison with the two better-known clusters in Beijing and Shanghai. Along the way it provides insights in the regional impacts of the post-Mao era reforms of scientific policy and the effectiveness of Chinese cluster-based regional and industrial policies.

- (2) One of the unresolved theoretical questions in the cluster literature is whether clustering in biotechnology creates innovation or whether innovation generates clusters (Orsenigo, 2006). The genesis and evolution of biotechnology clusters in Guangzhou and Shenzhen described in this paper provide a contrasting illustration of both hypotheses coexisting side by side in the same larger region. theoretical

² Since the clustering policies in the three regions are presented and critically analyzed by Tang and Prevezer (2006) and Zhang, Cooke and Wu (2011) they are not systematically treated in this paper.

- (3) What does China's experience with high technology clusters contribute to the theoretical debate on the complementary value of the three concepts used to describe biotechnology agglomerations in the literature?

- (4) Last, but not least, the concluding part of the study is assessing to what extent industrial applications of biotechnology have already contributed to transformation of Guangdong's industrial structure from labour-intensive, -low value-added export oriented activities into a high-tech, high- value-added knowledge-based economy.

The paper is structured in the following way. Section 2 provides a selective survey of the literature on the emergence of high-tech biotechnology clusters in developed western countries and in China.

Section 3 examines the structure, and evolution of the science and research system in the three regions, Beijing, Shanghai and GP. It benchmarks their resources and performance in biotechnology using Chinese official statistics and original analysis of scientific publications in Chinese BT journals and patenting of biotechnology inventions in China and the US.

Section 4 examines the industrial applications of biotechnology in the three regions. It is focused on manufacturing of biopharmaceuticals and medical equipment & appliances.

Section 5 examines the regional structure of biotechnology activities in Guangdong, focusing on the two major bio-regions: (1) the provincial capital Guangzhou (Canton) and (2) Shenzhen, the thirty years young city that became the manufacturing shop-floor of the world. A highlight of main results of our survey of biotechnology using firms and research institutions in Guangdong province completes the picture.

Section 6 is examining to what extent industrial applications of biotechnology have contributed to transformation of Guangdong's industrial structure from labour-

intensive, low value-added export oriented activities into to a high tech, high-value added knowledge-based economy.

Section 7 is discussing and interpreting the findings of the study and its contribution to the theoretical debate on genesis of clusters in science-based fields.

2. Review of the Literature

Agglomerations of high-technology firms, particularly biotechnology ones, have been analyzed using different concepts and theoretical approaches. Three among them deserve a closer look: innovative clusters (Porter, 1998), regional innovation systems (Cooke, 2002) and anchor-tenant based agglomerations (Feldman, 2003). We would argue that the three are related and are complementary.

2.1 Production cluster versus innovation clusters

A cluster is the geographic concentration of independent and informally linked companies and institutions in a particular field. “Compared with market transactions among dispersed and random buyers and sellers, the proximity of companies and related *institutions* in one location – and the repeated transactions among them fosters better coordination and trust”.... “In addition to enhancing productivity, clusters play a vital role in a company's ongoing ability to innovate” (Porter, 1998, p.80; 83).

Clusters arise because concentration of firms and industries in a region generates agglomeration economies from interdependencies in complementary activities that give rise to increasing returns and productivity and knowledge spillovers. In China, the manufacturing export production-oriented industrial clusters appeared first in government-established special economic zones in Guangdong province in Shenzhen, Zhuhai and Shantou. They are the source of China's rapid export-oriented industrialization (Zeng, 2011).

Industrial clusters thrive not only on low labor cost (often a rapidly vanishing advantage) but also on the accumulated experience of producing one type of narrowly defined products, a network of suppliers with sophisticated supply chains, design and engi-

neering skills, intimate knowledge of their production process and capacity to rapidly scale up production in response to arising opportunities (The Economist, 2012), describing in some detail the Chinese variety of production clusters and the evolution of their competitive advantage.)

Despite their huge popularity among decision makers, Porter's cluster theory and cluster-based policies have been criticized both on theoretical and empirical grounds (Martin and Sunley, 2003).

For the purpose of the present paper it is convenient to distinguish production clusters that conform to the general description above, from the high-tech innovation clusters in the fields closely related to the research near the scientific frontier, such as in biotechnology and medical devices.

2.2 Characteristics and advantages of high-tech innovation clusters

In high-technology fields competitive advantage is based on innovation, i.e. commercial application of scientific and technological advances. Innovation clusters are characterized by close contacts and informal communications among researchers in academia, research institutes and engineers, scientists, venture capitalists and other professionals in high-technology industries that provide specialized services, generating knowledge spillovers and encourage collective learning. These types of social interactions are typical of the internal dynamics behind the extraordinary achievements of the Silicon Valley ICT cluster and some other successful HT clusters (Bresnahan and Gambardella, 2004). However, as Feldman and Braunerhjelm (2006, p.1) argue, "the ingredients associated with Silicon Valley's success were not in place initially and Silicon Valley was not the obvious location for the computer industry".

Technology push policies such as the creation and support of Science and Technology Industry Parks (in China often called High-tech Industrial Development Zones-HTDZ) which provided physical infrastructure for clustering of enterprises in select H-T industries and related services are universally popular. However, empirical studies pro-

vide at best inconclusive evidence that firms in clusters perform better than those not located there. They do not perform better in the United States (Wallsten, 2004), nor in the UK (Watkins-Mathys and Foster, 2006), or in China, where the first HTDZ was established in Beijing in 1988, followed by 53 national HT parks by 1997 and many more founded by various levels of local government across China. (Zhang and Sonobe, 2011; Wang, and Li, 2010; Hu, 2007; Watkins-Mathys and Foster, 2006; Sutherland, 2005) These studies support the view that clustering alone is not conducive to higher innovative performance (Beaudry and Breschi, 2003).

More specifically, the literature on regional innovation systems in biotechnology (Cooke, 2002, 2004; Niosi, 2005) emphasizes the fact that “useful knowledge” is mostly produced in large metropolitan agglomerations, where research universities, R&D-intensive firms and public laboratories are located. This is in line with the anchor-tenant literature (Agrawal and Cockburn, 2003) underlining the importance of the establishment of one major firm, or in biotechnology a major research university or public laboratory (Feldman, 2003). Anchor tenants create positive externalities such as pools of skilled labor, knowledge spillovers and business opportunities for start-up firms attracting other R&D-intensive institutions and companies.

But as the regional distribution of US bioregions shows, only a few large university cities attracted biotechnology clusters. Scientific excellence is highly specialized and concentrated in a few regions. The first-mover advantages and increasing returns give rise to hierarchical global structures dominated by the few original, mostly U.S., bio clusters (Cooke, 2008).

Orsenigo (2006, p.217) concludes his critical overview of clustering in biotechnology: “...most of the case studies and the dynamic network studies (but also some econometric results) suggest that clustering is the outcome of a processes of construction and co-evolution of the conditions that allow clusters to exist, rather than the automatic effect of specific pre-conditions and agglomeration factors”. As Orsenigo and Tait (2008, p.400) note: “...geographical agglomeration results not only as an outcome of traditional externalities but also (and perhaps mainly) as a result of increasing returns, whereby clustering results from processes of spin-off (as distinct from spillovers) from knowledge-rich

organisations.” Based on this logic, it is easy to understand that, governmental interventions in planning (e.g. selecting winners and losers) and providing conditions that mimic the characteristics of successful mature clusters elsewhere may not bring about a successful bio-tech cluster.

2.3 Distinctive features of biotechnology clusters

Empirical research has identified several distinctive features of biotechnology clusters.

- Regional agglomerations of scientific and productive activities associated with application of biotechnologies are a product of a 'constructed advantage', namely establishment and funding of universities and public research institutes and laboratories (Cooke, 2006).
- Biotechnology can hardly be interpreted as a case where the knowledge within a cluster simply spills over (Orsenigo and Tait, 2008).
- Biotechnology clusters are not simply local, but they are open to interaction with other firms and institutions throughout the world. They are global (Orsenigo and Tait, 2008), forming hierarchical structures dominated by the few original, mostly U.S. bio- clusters Cooke (2006).
- The process of developing and bringing a new drug to the market may take ten years and the average cost (in the West) is about one billion dollars. The vicinity of research hospitals for clinical trials helps to create an innovation system (Cooke, 2002).
- Biotechnology enterprises are founded by or attracted to research institutions and universities and their “star scientists” (Zucker and Darby, 1996).

- Regional technological, rather than scientific, specialization may determine the growth trajectory specialization in continuing development of the industrial applications of biotechnology (Feldman, 2003; Orsenigo, 2001).
- The transfer of science from the laboratory to the market involves complex, interactive chains of transactions among scientists, entrepreneurs, and various intermediaries. Chief among the latter, in the US at least, are venture capital (Kenney, 2003) and law firms. However, VC's contribution to cluster success may be overrated (Horvath, 2004; Dellepiane, 2003). As Boston's example shows, an initial absence of venture capitalists is not an insurmountable obstacle to development of a successful biotechnology cluster. In contrast to the San Francisco Bay area where venture capitalists funded and oriented the business strategy of early biotechnology companies, the initial development and specialization of Boston's biotechnology firms was associated with and influenced by the regions' dense networks of strong public research organizations (Porter et al., 2005).
- The presence of Anchor-Tenant large firms Agrawal & Cockburn, 2003 or large research universities (Feldman, 2003) may encourage the development of the industry within the region.
- Biotechnology is heavily regulated. Regulation sometimes repels industry. However, as the example of the 'Cambridge Biosafety Ordinance' shows, a well-designed regulation encouraging informed public discussion attracted nascent biotechnology by providing clear guidelines reducing risks and public concerns (Feldman and Lowe, 2008)
- The role of entrepreneurs in biotechnology cluster formation as they react to impacts of changing opportunities and constraints is crucial and not well understood (Feldman et al. (2005).

- In emerging countries, industrial expertise, business know-how and choice of a strategy complementary of incumbents needs may be equally important as academic research infrastructure (Matthews, 2002; Zhou and Xin, 2003).

2.4 The current status and insufficiencies of biotech clusters in China

China created High-tech Industrial Development Zones incorporating a package of policies aimed at creating innovating clusters. The first was Beijing's Zhongguancun established in 1988, followed shortly by HIDZ in Shanghai, Shenzhen and several others (Yeung et al. 2009; Zhong et al. eds., 2009) Yuan et al., 2009). In their pioneering study of bio-clusters in China, (Prevezer and Tang, 2006) identified three major regional biotechnology clusters in P.R. of China, Beijing, Shanghai and Shenzhen in Guangdong province. Among important and original policies particularly important for the development of biotechnology in China their article emphasizes:

- the government decision to allow establishment of Minying Keji Enterprises (MKE)³,
- programs to attract back and support senior Chinese overseas scholars,
- the formation of scientific parks and incentives to BT firms.

The authors also underlined the problems associated with the strong government push for clustering that is substituting central planning for insufficient entrepreneurship

³ The Measures to boost the privately owned (Min ying, in Chinese) enterprises of the Government Guangdong Province which was issued in 2004 (in Chinese only)

<http://mky.gdstc.gov.cn/a/20087/2008731144734.asp>

This document mentioned to boost the development of four kinds of private-owned enterprises:

1. private-owned science and technology enterprises ('Min ying keji qiye' enterprises)
2. private-owned and trade-oriented enterprises
3. private-owned enterprises which aims at solving the unemployment
4. private-owned enterprises which aims at agriculture processing.

Segal (2003) argues that Beijing policy makers left what constitutes a '*Min ying keji*' enterprise intentionally vague so as to allow different regions to experiment with various forms of enterprises that were not any more controlled by the government. In Guangdong Province they are called 'private-owned_High-Technology enterprises'. Segal adopted the term *nongovernmental enterprise* in the sense that they are not under direct governmental control. A state-owned enterprise can also be '*minyong qiye*', suggesting that the ownership control is not the decisive criterion. An alternate preferred term is *privately run enterprises*.

and induces firms to act in response to government incentives rather than to market conditions. However, their account neglects to mention the positive role of government policy in building up in Shenzhen the indispensable higher education and research infrastructure (see Chen and Kenney (2007) who contrasts the experience of Beijing and Shenzhen clusters with respect to universities and research institutes).

In a recent article Zhang, Cooke and Wu (2011) analyze the government-sponsored development in China, including creation of Science and Technology Parks in Beijing, Shanghai and in Guangzhou-Shenzhen, the two major centers of biotechnology in Guangdong Province. They recognize the benefits of state intervention in the initial stages of BT development and the helping hand of regional and municipal governments. However, they warn that in the absence of well-developed sources of venture capital and mature pharmaceutical industry, the government funding will be insufficient for the sustained development of BT industry.

Long and Zhang (2011) argue that in addition to the potential benefits of agglomeration and knowledge externalities, clustering of export-oriented, labor intensive, manufacturing firms favors inter-firm trade credit arrangements, thus reducing their reliance on external financing for working capital.

However, inter-firm cooperation is rare in China. Conlé and Taube, 2012 observed in certain clusters downright mistrust. They argue that owing to the failure of the capital market to provide up-start pre-revenue firms with sufficient funds, firms opt to collect funds offered by local government cluster-creating policies by establishing manufacturing subsidiaries in various locations – clusters, parks etc. This ‘rent seeking’ approach has an impact on the firms' localization decisions and their business strategies, which, in turn, affects the “culture” inside the clusters. This may explain the notorious lack of the “creative buzz” in Chinese high-tech clusters

The technology push policies such as the creation and supporting Science and Technology Parks are universally popular but they rarely deliver their promise. Neither in the U.S. (Wallensten, 2004), nor in the UK or for that matter in China exists evidence that

firms inside parks⁴) perform better than those not located there (Zhou and Feng (2004), Watkins-Mathys and Foster, 2006; Wang and Li (2010). For more information on Chinese Science parks, see Tang (2008) and Cheng et al. (2013).

According to Zhang et al. (2011) the links between university, research institutes, and industry are generally weak in China. They argue that it is the result of top down government funding of research programs rather than horizontally among research institutes and firms. With respect to this finding, MacDonald and Deng (2004) goes even further suggesting (1) that the Science and Technology Park concept of technology transfer is simplistic because it is based on the discredited linear model of innovation, and (2) the university-owned firms who are the principal users of park's services are in essence state owned enterprises managed by academics with little entrepreneurial know-how and skill. These and other studies suggest that for the success of an innovation cluster the social relationships among various players are more important than infrastructures and institutions provided by the governments.

-2.5 Contribution of entrepreneurs

The conventional explanations of the success of Silicon Valley credit the pre-existing or the purposely constructed conditions and particularly the institutional setup of the region. Feldman and Braunerhjelm (2006) disagree and argue that these views ignore the historic development of these institutions and the way they have coevolved." They ignore the essential role played by entrepreneurs. According to Feldman and Lowe (2005) study of the emergence of a biotechnology cluster in Washington D.C., clusters in new industries emerge organically due to the collective action of entrepreneurs shaping the local environment to advance the interests of their emerging industry.

In the case of China, the Central government initiated after 1978 reforms that created new opportunities and challenges. The open door policy led in 1980 to creation of the first Special Economic Zones (SEZ) in Guangdong province in Shenzhen, Zhuhai and Shantou⁵ Business entrepreneurs emerged creating privately-run MKE firms. The local

⁴ China's Scientific and Technology Industry Parks differ from science parks in other parts of the world in that they are oriented to the production of hi-tech goods (especially for export), as well as R&D in hi-tech clusters (Watkins-Mathys and Foster, 2006).

⁵ Followed two month later by the 4th SEZ in Xiamen (Fujian province).

government in cooperation and coordination with the emerging business class was introducing market mechanisms, in the Chinese context of that time a social innovation of the first order, attracting foreign direct investment and launching export-oriented industries. Owing to its innovating policies Shenzhen rapidly surpassed the other three SEZ by a large margin (Yeung et al., 2009; Zeng .2011).

The innovators, both businessmen and the municipal government, recognized early the need for local higher education institutions to attract, train, and retain qualified manpower. Shenzhen founded university and research institutes, and attracted spinoffs from the top Chinese universities and the Academy of sciences research institutes (Chen and Kenney, 2007). The research infrastructure was created in response to the demand from the enterprises building the emerging high-tech clusters.

3. The Biotechnology Regional Innovation Systems in Beijing, Shanghai and Guangdong

At the beginning of the post-Mao era Chinese national innovation system underwent important reforms that modernized the national innovation systems and created a new, more modern framework within which evolved the regional innovation systems of the three provinces. This transformation from a centrally planned to a more modern and less tightly centrally controlled innovation space system is useful for the understanding of similarities and differences among the three regional biotechnology innovation systems (or clusters) in Beijing, Shanghai and Guangdong.

3.1 The national science and technology system before the beginning of reforms

The distinctive characteristics of the Chinese National Innovation System changed dramatically since the start of reforms in 1978. Initially, almost all scientific research was performed in Government Scientific Research Institutes (SRIs). The most prominent was (and still is) the Chinese Academy of Science (CAS) under the direct control of the Central government. In addition there were many SRIs responding to Central ministries, Provincial as well as municipal governments. Universities were dedicated to undergraduate

education utilizing knowledge from advanced countries and most of them did not engage in research. Only a limited number of key universities were conducting some applied research for industrial enterprises (Xue, 2006).

One of the early Chinese success stories in the realm of advanced biotechnology research was creation of the first artificial bovine insulin⁶ in the world in 1965, result of collaboration among the Institute of Biochemistry in Shanghai, the Shanghai Institute of Organic Chemistry of the Chinese Academy of Sciences and the Department of Chemistry in Beijing University.

Before reforms industrial enterprises were responsible for execution of the planned production targets fixed at higher political and administrative levels. The role of enterprises in strategic decision making was limited or inexistent. Only few of the large firms did some development. When needed for introduction of new technology process or product technology, the R&D was entrusted to the appropriate SRI.

This division of tasks between SRI, Higher education (HE), and industry, characteristic of socialist planning, was inefficient and hampered innovation. There was a huge gap between what the SRI did and what firms needed. Industry therefore had to rely on imitated and imported technology (OECD, 2009).

3.2 Reforms of the national innovation system

China's transition to a more market oriented economy was marked by a fiscal and administrative decentralization, gradual relaxation of restrictions to private enterprise and redefinition of ownership rules in the urban economy. The 'Open Door Policy' reforms that begun in 1978 aimed at attracting foreign advanced technologies and management techniques in exchange for access to China's internal market. Throughout the 1980s the central government implemented a regional decentralization policy "One China, many economies", allowing the local authorities to experiment with introduction of a market economy. One of the policies was to relax the strict governmental control at micro-level

⁶ www.chinatech gadget.com/chinas-breakthrough-in-biological-sciences

and allow emergence of MKE collectively or later /privately run enterprises. The strategies of technological and industrial development were determined by the response to different initial conditions in the three regions.

3.2.1 Beijing

The initial situation in Beijing was radically different from the rest of China. Before the reforms the capital was the center of scientific research concentrated in a large number SRIs. Even though their research was mostly applied rather than fundamental, the transfer of their technologies to industry was not successful. In high-tech fields industrial enterprises did little or no research and were lacking the absorption capacity needed to assimilate new science-based technologies. Reforms drastically reduced the number of SRIs by cutting funding and transforming many research institutes into enterprises, introducing competition, and encouraging SRIs, and also universities, to set up companies (Chen and Kenney, 2007). In fact, universities and SRIs started to establish and run enterprises.⁷

Beijing local government was the first in China to promote creation of nongovernmental; privately run high-technology enterprises (*minying qiye*) trying to emulate the Silicon Valley regional innovation cluster (Segal, 2003)⁸. Most of these enterprises were affiliated with the Chinese Academy of Sciences in Beijing and about fifty of them, mostly in ITC, were listed on stock markets.⁹

⁷ The structural reforms of the S&T system started in 1985 and its first phase marked by introduction of major programs was completed in 1995, the year marked by introduction of ‘Revitalization of the Nation through science and education strategy’ that saw deepening of the S&T reforms (OECD, 2008). In 1997 there were 6634 university run enterprises in China, many of them quoted on the stock market. Several of the most successful PC makers (Lenovo, Founder and Tongfang) are firms established and run by SRIs or universities. However, in response to criticism that the trend to URE handicaps universities’ primary responsibility of training, the policy was reversed in 2001 and the number of university run enterprises declined to 4563 in 2004 (Eun, 2006 et al.).

⁸ Beijing is the center of Chinese higher education with 20% of the top 100 Chinese universities. Many of them actively cooperate on research projects with industry or provide technology services. The most original form is the setup of university-run (URE) HT enterprises (another form of ‘*minying qiye*’ enterprise) where Beijing leads the rest of China. In terms of their economic performance ranked by income rank by region, Beijing URE have been consistently in the first place, followed by the URE from Shanghai and only in the distant fifth rank are URE from Guangdong (Chen and Kenney, 2007).

⁹ As of 2004, there were about 400 HT enterprises affiliated with CAS in Beijing (Eun et al. 2006).

In 1991 many new privately-run enterprises were located in the newly established high technology development zone Zhongguancun (see detailed analysis of Beijing's H-T enterprises, especially Electronics and ICT by Segal, (2003). These non-governmental enterprises in Beijing benefited from the start from grants, tax exemptions, tax credits for R&D, preferential VAT tax and export subsidies. However, in contrast to SOE, nongovernmental enterprises had to fend for themselves and, if not profitable, were allowed to face bankruptcy.

3.2.2 Shanghai

Shanghai's economic structure and technological development at the outset of economic reforms was dominated by large State-owned enterprises. Even though Shanghai was in some fields almost as well endowed with research institutes and first class universities as Beijing, its initial development strategy was in sharp contrast with that of Beijing and Guangdong. Instead of extending the boundaries RSIs research universities by allowing them to create and run high technology enterprises and helping them to thrive as the municipal government did in Beijing, Shanghai government concentrated efforts and funds on improving the technological level of their large SOEs and neglected the creation and development of *minying* nongovernmental enterprises.

A contributing factor to Shanghai administration's attitude was, according the Segal (2003), the long standing role of Shanghai's economy as a major contributor to China's national budget. Between 1949 and 1983, about 87 percent of the Shanghai city government's revenue was remitted to the center. Another factor was Shanghai's almost complete elimination of private industry by 1956 and replacement of the former light industries by heavy industry indispensable to development of the rest of Chinese economy. In many ways, Shanghai's economy was not autonomous; it was directed from Beijing by and for the Central government. The central planners from Beijing were leery to let Shanghai municipal government experiment with new forms of development that could put in jeopardy whole Chinese economy.

3.2.3 Guangdong Province

At the beginning of the economic reform after 1978, the industry of Guangdong Province, especially in the capital Guangzhou, was specialized in old, labor intensive industries, with mostly small and medium size enterprises. Its main advantage was abundant low cost labor and the proximity to Hong Kong. The development strategy was to strengthen Guangdong Province's export capacity in labor intensive goods and use Hong Kong as the door to the world. To achieve this goal the National People's Congress created in 1980 -1984 Special Economy Zones in Guangdong Province in Shenzhen, Zhuhai and Shantou to experiment with opening of the economy to international trade, foreign direct investment (FDI) and private enterprise in a relatively free market. Opening to international trade and foreign direct investment was expected to be the driver of the necessary learning and technological upgrading. It succeeded to attract labor intensive industries from Hong Kong and Taiwan that were losing their low labor-cost advantage. Shenzhen, a small fishing village before the reform, rapidly became China's leading export-oriented manufacturing center.

In Guangdong Province the creation of non-state-owned and controlled enterprises, first under the banner of collective enterprises and later as private enterprises was more focused on developing exports than developing high technology. The local governments did not intervene in the daily business operations of private firms but they also did not sought to correct market failures, nor did they try to introduce measures facilitating and improving technological development. It was expected that foreign investors, be it firms from Hong Kong or Taiwan, foreign MNC or Chinese returnees, would provide the capital and the indispensable knowledge and technology development for export-based growth and enable Guangdong industry integrate into international value chains (Segal, 2003; Arvanitis, 2006).

3.3 The innovation systems in the three regions today¹⁰

The national and regional innovation systems rely on R&D activities in three main types of organizations: (1) scientific research institutes (SRIs), (2) academic research at universities and (3) industry- enterprise sector research and development. The experience of innovation clusters in the US and Europe has demonstrated that this is best achieved when universities and SRIs are an integral part of an open regional innovation system, have close contacts with enterprises and few barriers to people moving between academy and industry (Audretsch and Feldman, 1996; Niosi and Bas, 2001; Cooke, 2002; 2004; 2008).

3.3.1 Scientific infrastructure-resources and activities of the main actors

(i) *Scientific Research Institutes*

More than thirty years after the introduction of economic reforms, China's scientific activities are still highly concentrated in the capital. According to China Science and Technology Statistical Yearbook 2010, over seventy thousand (full time equivalent) R&D personnel conducted R&D activities in Beijing's 353 scientific research institutes¹¹ in 2009. In comparison, there were about 22 thousand R&D personnel in Shanghai's 134 SRIs and about seven thousand personnel in 183 SRIs in Guangdong Province. SRIs main role is to perform fundamental and applied research. The combined share of the total number of S&E dedicated to basic and applied research was similar (about 60%) in the three regions. However, the relative importance of basic research is higher in Beijing (about 25%) than in Guangdong (20%) and Shanghai (18%).

¹⁰ The scientific and technological infrastructure of the Guangdong province is concentrated in Pearl River Delta, more specifically in the provincial capital Guangzhou and in and around Shenzhen. A comparison of the more urbanized and economically developed PRD region with the two city-regions Beijing and Shanghai would be our preferred choice. Unfortunately, the comparable statistics are available only on the provincial level including Guangdong and the city-regions Beijing and Shanghai.

¹¹ See Science and Technology Yearbook (S&T), 2009, Table 3-3, and 2008, Table 2-7 for the ratios of employment of Scientists & Engineers/Full time equivalent R&D personnel.

(ii) *Higher education sector*

Scientific research in natural sciences is also conducted by Universities. Again, Beijing is leading the three regions, with some forty higher education institutions employing in all scientific disciplines eleven thousand scientists with a doctoral degree, compared to 17 institutions and seven thousand PhDs in Shanghai and 37 academic institutions but only about four thousand doctoral level researchers in Guangdong.¹² However, a comparison of the number of scientific publications in biotechnology published by ten leading universities in each of the three regions (see further below) shows a less contrasted picture.

3.3.2 R&D in industrial enterprises

In contrast to the concentration of research in public and academic research institutions in Beijing, and to a lesser extent in Shanghai, the dominant share of R&D (in fact mostly D-development) in Guangdong province is executed by export-oriented industrial enterprises,¹³ many of them foreign-invested from Hong Kong, Taiwan and Macau.¹⁴ After the initial wave of labour-intensive export-oriented industrialization in special economic zones, the industrial structure in GD Province is shifting toward more R&D intensive high value-added industries Oizumi K. (2011). To be able to adopt and assimilate advanced foreign technologies the local firms had no choice but to start R&D activities. Owing to Guangdong's high degree of industrialization, the enterprise sector there accounted for one third of Chinese total High-Tech Industry Intramural Expenditures on R&D in 2009.

The overview of the three main sectors of the scientific and technological infrastructure and their activities in the three regions shows that there is a clear pattern of regional specialization. The scientific research dominates the regional innovation system in Beijing region. Owing to its high industrialization, the strong entrepreneurial tradition

¹² S&T Yearbook 2009, Table-4-3

¹³ S&T Yearbook, 2010, T-2-13

¹⁴ The bulk of FDI came to Guangdong from Hong Kong, Macau and Taiwan before mid-nineties and was concentrated in the low value-added labor intensive manufacturing and assembly work not in science intensive industries such pharmaceuticals or BT.

and fewer scientific research institutes and universities, industrial R&D is stronger in Guangdong province than in Beijing or Shanghai. The innovation system of Shanghai is between those two extremes. Its scientific infrastructure, the number of national level SRIs and top universities with affiliated enterprises in several scientific parks, is stronger than in Guangdong, but weaker than in Beijing. On the other hand, owing to the smaller scale of its industrial sector, the total industrial R&D expenditures in Shanghai are lower than in Guangdong (Table 1).

3.4 Returnees

An overview of China's innovation system would be incomplete without mentioning the extraordinary contribution of returnees (called sea turtles in Chinese), i.e. Chinese students, researchers, university professors and businessmen returning to China with high qualifications and experience acquired while studying and working abroad, mainly in the US, EU and Japan (for more on returnees in China's biotechnology clusters see Prevezer and Tang, 2006 and Qiu, 2009).

Table 1
Intramural Expenditures for R&D by Performing Organizations (2009)

	Total	Research Institutes	Higher Education	All Enterprises* Except HT	HT# Enterprises	Other
China Total	58 021 068	9 959 481	4 681 449	37 128 835 898	8 921 215	5 623 025
	100,0%	17,2%	8,1%	49,7%	15,4%	9,7%
Beijing	6 686 351	3 216 954	700 453	682 311	454 719	1 631 914
	100,0%	48,1%	10,5%	10,2%	6,8%	24,4%
Shanghai	4 233 774	869 512	402 285	173 2129	633 021	596 827
	100,0%	20,5%	9,5%	40,9%	15,0%	14,1%
Guandong	6 529 820	175 980	239 879	2 548 698	2 975 035	590 228
	100,0%	2,7%	3,7%	39,1%	45,6%	9,0%

Source: China S&T Yearbook, 2010, Tables T1-7; T3-7; T-4-5; T2-19.

Note : *These are "Enterprises above the designated size (i.e. those with annual Revenue from Principal Business over 5 Million Yuan).

#High-Tech Medium and Large size Enterprises.

Even while abroad, Chinese immigrant scientists and engineers are exchanging technical information with professional contacts in China and invest in partnerships

(Saxenian et al, 2002)¹⁵. Those who return¹⁶ bring back to China not only frontier scientific and technological knowledge, but often even more important practical experience, professional contacts and Western attitudes to research and business not to mention the important language skills.¹⁷ Well aware of the contribution of returnees, China has launched the *Thousand Talents Program* to attract “sea turtles” (as they are called in Chinese) back home (Lundh, 2011). In certain fields, such as biotechnology, China’s provincial and municipal governments are providing the laboratory space, infrastructure needs and start-up research grants to highly qualified returnees. With the rise of China’s economy and economic problem in the West, the proportion of Chinese students and researchers returning from abroad has been sharply increasing. However, integration of returnees in Chinese research laboratories and enterprises is not without problems (Yi, 2011).

3.5 The Biotechnology Innovation Systems in the three regions

The aggregate data on R&D expenditures by province in Table 1 above hide very large sectorial differences.¹⁸ Unfortunately, the statistics on R&D employment or expenditures by scientific research institutions (SRI) and universities in BT are not available.

¹⁵ In Silicon Valley 82% of Chinese and Indian immigrant scientists and engineers report exchanging technical information with their respective nations; further 18% invest in business partnerships.

¹⁶ According to Ministry of Health, there have been 150 000 returnees in 2007 to 2009, 69 300 in 2009 alone, a 69% increase over the year earlier (Daverman, 2010).

¹⁷ China’s Ministry of Education estimates that one-quarter of the 700,000 students who left China between 1978 and 2003 have now returned (Lundh, 2011).

¹⁸ A major problem in analyzing the regional evolution of modern biotechnology(BT) in all countries is the fact that owing to its generic character there are few reliable data for industrial applications of BT. In contrast to most other countries which do not yet include BT applications as a separate category in their economic statistics, China has classified *Manufacturing of biological and biochemical products (MBBP)* as a sub-category of *Manufacture of medicines and pharmaceutical products (MMPP)* and published statistical series from 1995. *Manufacturing of medical equipment and appliances (MMEA)* is using among other technologies also modern BT, but the biotechnology content is not reported.

Most of the national data for MMPP and some for the MMEA are available by province, but the finer breakdown specific to BT MBBP is rarely reported on the provincial level. Some data on MBBM exist in provincial statistical documents, but their format is rarely comparable between provinces. Since according to the literature about 75-80% of biotechnology applications are used in manufacturing of biopharmaceuticals, the size, structure and evolution of pharmaceutical industry gives an approximate order of magnitude of the growth of production of biopharmaceutical products and processes in health sciences, the field for which BT holds the greatest promise. The recent reclassification of high-tech industries, including BT, is a step in the good direction. Unfortunately, most available statistics are still using the old classification system.

The scientific research creates new knowledge diffused by scientific conferences, personal contacts and scientific publications. Bibliometric analyses of publications are used as indicators of the research performance. The bibliometric analysis of scientific articles on biotechnology reveals the scientific prowess and also the patterns of collaboration (co-authorship) between academic and research organizations and the industrial enterprises. The patentable results of applied research and development provide another metric for evaluation of the performance of the regional innovation system. Both, the bibliometric analysis and patent analysis suffer from a series of well-known shortcomings. Despite their imperfections, both are abundantly used because there are often no better alternatives available.

3.5.1 Performance of biotechnology-related scientific research

The scientific production of universities in the three city regions was assessed using the China National Knowledge Infrastructure bibliographic information on publication of scientific articles written in simplified Chinese language in the field of biotechnology and bio-medical equipment¹⁹ from 1980 to 2012. To make the search manageable, it concentrated on the top universities and research institutes of the CAS from Beijing, Shanghai and Guangdong province that published in the biotech-biomedical field at least ten²⁰ scientific articles. Also included were publications that list as the first author a person affiliated with an enterprise. The results are presented in Table 2.

As expected, Beijing had more highly performing universities (20) than Shanghai (16) and Guangdong (16). Beijing top universities published more scientific articles in biotechnology than their counterparts in Shanghai (22%) and Guangdong (43%). A similar search of institutions affiliated with the CAS shows even larger regional differences in

¹⁹ The search included the following disciplines: fundamental science, science of engineering and technology, agriculture science and technology, health sciences and technology, social science and technology of information. Philosophy, human sciences, economics and business administration were not included.

²⁰ Statistics for Guangdong province represent the sum of publications by organizations located in Guangzhou and Shenzhen, the two main centers of biotechnology activities in the province. With regard to their young age, three of the five Shenzhen universities were included even though they had less than 10 published articles. Had those articles not been included, the total count of publications for Guangzhou & Shenzhen would be 1082 instead of the 1100 in the Table.

the number of research institutes engaged in biotechnology research. There are 16 CAS research institutes in Beijing, 8 in Shanghai and only 6 in GDP that published articles on biotechnology.

The successful regional innovation clusters benefit from knowledge spillovers generated by personal contacts and interactions among academic and professional researchers and industrial enterprises. The intensity of co-authorship is one indicator of such interactions. Co-authorship in the three regions is infrequent. Overall, less than 5% of articles were the result of collaboration between authors affiliated with different universities and/or CAS institutes. The collaboration between universities and industrial enterprises in the same province is even less frequent, at about 2%. The share of co-authored articles, between enterprises and universities in the same region, is somewhat higher in Guangdong than in Shanghai or Beijing. Co-authorship between researchers from the CAS and enterprises is negligible.

When the search focused on the scientific publications by enterprises²¹ those in Beijing authored 186 articles, in Shanghai 128 and in GDP 100 articles (Table 2, third panel). A large proportion of those articles have been written in collaboration with authors affiliated with universities. It suggests that the collaboration between industry and universities is more frequent in Guangdong than in the two other city-regions. Thus the overall conclusion of these numbers suggests that there is a large gap in publications of CAS research institutes between Guangdong, Shanghai and Beijing, and that these are strongly concentrated in the capital region. In comparison, regional disparity is less pronounced for university research. On the other hand, even though enterprises in Beijing and Shanghai publish more than those in Guangdong, in relative terms, industry-university co-publishing is more intensive in Guangdong than in Shanghai and Beijing.

²¹ The search in Chinese used the words «Gongxi » or «Qiye» (i.e. “enterprise” in Chinese Pinyin) to find publications by enterprises. For this reason it may have missed some companies which do not include the word “enterprise” in their official name and the actual number of publications by enterprises may be larger than reported in the Table.

Table 2
Scientific Publications and Co-publication with Enterprises, by Organization and by Region
 (Number of scientific publications in Chinese biotechnology publications, 1980-2012)

The 1st Author affiliated with:		Collaboration	
UNIVERSITIES (Number of publications included)	Number of publications	Co-authored with enterprises located in	
		All provinces	Same province
Beijing (20)	1577	66 (4.2%)	33 (2.1%)
Shanghai (16)	1283	78 (6.1%)	24 (1.9%)
Guangdong (16)	1100	43 (3.9%)	31 (2.8%)
CHINESE ACADEMY of SCIENCES (Number of publications included)		Co-authored with enterprises located in	
		All provinces	Same province
Beijing (16)	629	9 (1.4%)	3 (0.05%)
Shanghai (8)	189	1 (0.5%)	0 (0.0%)
Guangdong (6)	65	0 (0.0%)	0 (0.0%)
ENTERPRISES	Enterprises that published	Co-authored with universities located in	
		All provinces	Same province
Beijing	186	n.a.	57 (30.6%)
Shanghai	128	n.a.	28 (21.9%)
Guangdong	94	n.a.	45 (47.9%)

Source: Authors' computation using China National Knowledge Infrastructure (CNKI) bibliographic information. Publications in Chinese language only. The sample includes universities and CAS' research institutes with at least 10 scientific publications in biotechnology from 1980 to 2012.

Notes: The number of publications is ordered by affiliation of the first author. For example, 1577 articles list as the first author a person affiliated with one of the 20 Beijing universities included in the search. Out of these, 55 (3.5%) articles were co-authored with researchers from other Beijing Universities, 33 articles (2.1%) co-authored with authors from Shanghai enterprises and 75 (4.8%) with authors affiliated with CAS.

3.5.2 R&D in pharmaceutical and biopharmaceutical industry

In all three regions, the majority (about 60%) of pharmaceutical firms still do not engage in R&D activities. Thus, the minority 40% of firms active in R&D are in fact on average performing about 2.5 times more R&D than the reported industry average suggests. The low proportion of firms active in R&D compares still advantageously with the overall average of 30% of R&D performers in all high-tech industries in China. But it also shows how far behind the Chinese pharmaceutical industry is in comparison to western biotech and pharmaceutical firms.

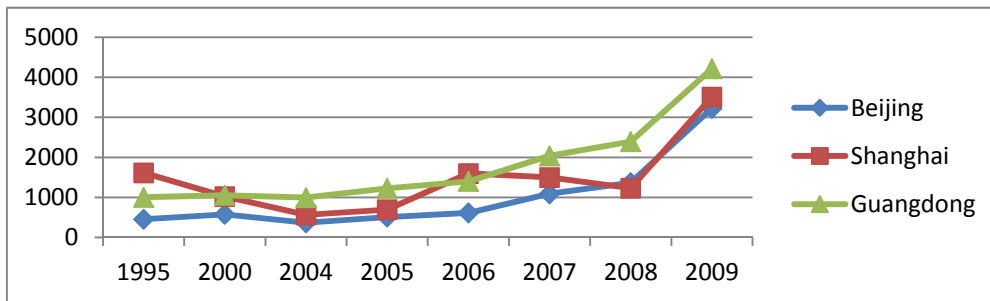
Systematic data on biotechnology R&D activities in industrial enterprises is not available at the provincial level. But it can be safely assumed that R&D activities in the “*Biological and Biochemical Products*” industry were increasing at least as fast as in the pharmaceutical industry on the whole. The evolution of R&D employment in the pharmaceutical industry presented in Figure 1 shows that Guangdong was leading both Beijing and Shanghai over the whole 2000-2009 decade. However, as of 2009, research intensity, the ratio of R&D employment to total employment in the pharmaceutical industry in Guangdong was about 4%, inferior to that in Shanghai and Beijing, where it was about 6%.²²

The R&D activities of the enterprise sector concentrate on development rather than scientific research. Most of them focus on learning about and assimilation of foreign bio-technologies and their adaptation to local conditions. As with other industries, foreign enterprises play a very important role in diffusion of modern technology to China,

²² Source: High Technology Industry Yearbook 2010, Tables 1-2-9 and 2-2-9 for 2009. Full time-equivalent R&D employees /Total employees. Note that the R&D statistics cover only medium and large size H-T enterprises. The picture they provide underestimates the reality of the dedicated biotechnology enterprises that are small and not included!

especially in Guangdong, where, like in Shanghai, they account for about 50% of assets in manufacturing.²³

Figure 1
Full-time Equivalent R&D Personnel in Medical and Pharmaceutical Products Manufacturing
 (Large and medium size H-T enterprises)



Source: HT Industry Yearbook, 2008, Table 2-155 and HT Industry Yearbook 2010, Table 2-2-9 for 2009.

Notes 1. Statistics on R&D in smaller enterprises are not available.

2. Data for R&D in Manufacturing of biological and biochemical products (MBBP) industry by province is not available. It represents a small but increasing share of Medical and Pharmaceutical Manufacturing.

3.5.3 Patenting of biotechnology inventions in China and the U.S.

Patent statistics, imperfect as they are as indicators of innovation in some industries, are a recognized and a valid indicator of the technological prowess in pharmaceutical industry as well as in manufacturing of special equipment such as the medical instruments and devices. Products of these industries were not patentable in China until the first amendment of the patent law in 1992-1993 that made the Chinese patent law compliant with TRIPs standards even before their official enactment in 1995, and well before China's admission to the WTO. The compliance with the TRIPs was completed in the second amendment in 2000.

²³ Guangdong received about 30% of China's total FDI, most of it from Hong Kong (66.2% cumulative FDI inflows from 1979-2004), Taiwan 5.9% and Macau 4.5%. In 2004 close to ¾ of all FDI was in the province was invested in manufacturing industries (Huang and Sharif, 2009).

(i) Patenting in China

After a slow start, patenting in China took off rapidly in 1998 and has further accelerated since 2004.²⁴ The number of patents for biotechnology inventions increased from 190 in 2004 to 771 in the beginning of 2009 (the latest period covered in our data base). The patent statistics in Table 3 show significant regional differences with respect to the number of patents and their ownership. The largest number of patents (681) was granted to Beijing organizations and individuals, followed by those in Shanghai (373) and Guangdong province (289). Beijing's patent scene is clearly dominated by the numerous research institutes which account for almost half of all biotechnology patents granted to Beijing (48.9%), compared to one quarter of patents owned by universities. This contrasts with the situation in Shanghai and Guangdong, where universities own two to three times more patents than the local research institutes.

Enterprises patent relatively little in Beijing (17.4%). They are more active in Shanghai (24.9%) and even more in Guangdong (30.4%), where their share of patents is not far behind universities (35.6%).

Co-patenting is one of the indicators of collaboration in R&D. Surprisingly, even though enterprises in Beijing patent relatively less than those in the other two regions, they collaborate more, mostly with other enterprises and universities. However, not a single patent granted to an enterprise lists a research institute as co-owner and among the 298 patents granted to research institutes only three were developed in collaboration with an enterprise.²⁵ Research institutes in Beijing collaborate mostly with other institutes and, less frequently, with universities. The patent statistics suggest that the Beijing biotechnology cluster, dominated by research institutes associated with the Chinese Academy of

²⁴ Patenting by Chinese nationals is rewarded by monetary incentives offered by the regional and municipal governments in the case of domestic patent applications and patent awards and by the central government in the case of patenting abroad. As an example (the rates and conditions vary from region to region) the City of Zhangjian, was granting in 2006 a subsidy of 3 000 Yuan for patent application and 1000Yuan for a patent grant, thus covering a significant portion of patenting cost (Lei, Sun and Wright, 2012).

²⁵ The breakdown of patent counts by the type of organization listed as co-patentees not presented in the Table 4 is available on request.

Sciences and Military Academy of Medical Sciences is more focused on advancing knowledge than its industrial applications.

In Guangdong Province, and to a lesser extent in Shanghai, universities and enterprises are relatively more active in biotechnology patenting than in Beijing. However, their co-patenting with enterprises is even less frequent than in Beijing.

The ranking of top patentees in the three regions shows that top universities patent even more than research institutes. This illustrates the profound change in their vocation in response to funding incentives (Table 4). Guangdong province's *Sun Yat Sen University* and the *Yi Tai Shenzhen* enterprise lead in their respective categories.

The high patenting propensity of institutes affiliated with the Military academy of medical sciences in Shanghai is a reminder of the importance of the People's Liberation Army in the scientific infrastructure under the direct control of the central government in the capital.

Table 3
Number of Biotechnology Invention Patents Granted by the Chinese Patent Office, by Region and Type of Owner, (2002-2009)*

Organization	Beijing			Shanghai			Guangdong		
	Patents	% of total	% co-owned	Patents	% of total	% co-owned	Patents	% of total	% co-owned
Enterprises	106	15.6	18.9	99	26.5	6.1	88	30.4	2.3
Universities	156	22.9	9.6	136	36.5	5.9	106	36.7	7.5
Research Institutes	298	43.8	7.7	67	18.0	23.4	36	12.5	16.7
Hospitals etc.	53	7.8	3.8	36	9.7	5.6	28	9.7	0.0
Individuals	68	10.0	16.2	35	9.4	8.6	31	10.7	16.1
Total	681	100.0	10.4	373	100.0	9.4	289	100.0	7.6

Source: SIPO, China, invention patents from 2002 to 2009/1st Q, assigned to Chinese patentees in international patent classes for biotechnology (OECD, 2009).

Note. The percentage of patents with two or more owners (assignees) is classified by the 1st owner only. For example, a patent whose 1st owner is an enterprise and the 2nd owner is a university is classified in the row Enterprise. The underlying assumption being that the first-listed owner had a more important role than the following owners.

**Table 4
Top Chinese Patentees in Biotechnology, 2002 -2009**

Rang	Organization	Region	Type	Patent counts	
				Solo	Incl. Co-patents
1	University Sun Yat Sen	Guangdong.	U	53	59
2	Shanghai Jia Tong University	Shanghai	U	40	41
2	China Agricultural University	Beijing	U	40	41
4	Tsinghua University	Beijing	U	35	38
5	Beijing University	Beijing	U	36	0
6	CAS-Shanghai Inst. Of Org. Chemistry	Shanghai	R	33	0
7	CAS-Institute of Botany	Beijing	R	33	0
8	Second Military University	Shanghai	U	31	32
9	Enterprise Yi Tai -Shenzhen	Guangdong	E	31	0
10	CAMS- Institute of genetics and development biology	Beijing	R	28	29
11	CAS- Shanghai institute for biological sciences	Shanghai	R	25	30
12	Pop. Liberation Army Inst. of pharmacology and toxicology	Beijing	R	19*	(74)* 0

Source: SIPO, China, invention patents from 2002 to 2009/1st Q, assigned to Chinese patentees in international pat. classes for BT (OECD 2009).

Notes. * This is the most successful patentee among the top five institutes affiliated with the People's Liberation Army Academy of Medical Sciences. Their combined patent count is 74, no co-patenting reported..

Patenting of biotechnology inventions in the USPTO

Patenting in China is however not the best indicator of the originality and technical quality of inventions, especially relative to the international competition. This purpose is better served by the capability of Chinese organizations to obtain a patent abroad. Since the US is the most competitive and largest biotech market, a US patent is universally considered seal of technological prowess sought by all players in the field of modern BT.

The number of BT patents invented by Chinese nationals and granted to Chinese organizations (CN assignees)²⁶ by the US patent office from 1995 to 2009 confirms the leading position of Beijing (57 patents), followed closely by Shanghai (46 patents) with Guangdong far behind with only 9 patents.

²⁶ Source: Authors computation using the U.S. Pat office search engine. Note that only patents in BT classes according to the OECD definition granted to mainland Chinese assignees are taken into account (Hong Kong, Macau and Taiwan not included).

In terms of patenting in the U.S. where it counts most, the Guangdong region is clearly lagging behind the two other regions.²⁷

3.6 Imports of technologies from abroad

The Diffusion of foreign technologies proceeds by two principal channels: (1) market transactions and (2) various technology spillovers.²⁸ While it is difficult to measure the spillovers, the information on market transactions, i.e. the cost of imports of foreign technology (licenses, know how, intellectual property etc.) is available in the H-T statistics.

At their peak the cost of foreign technology amounted to 64% of intramural R&D expenditures of MMPP industry in Guangdong (2004), 43% in Shanghai (2000) and 30% in Beijing (2005).²⁹ The expenditures on foreign technology show first a sharp increase followed by an equally sharp decline (Figure 2). The amplitude of fluctuations is probably intensified by large one-time technology acquisitions and/or an abrupt change in government policy with respect to imports of foreign technology. On the other hand, the declining trend of the ratio of foreign technology imports to intramural R&D expenditures that started in 2000 in Shanghai, then in 2004 in Guangdong and in 2005 in Beijing may reflect the effect of increasing R&D activity in China with respect to imports of foreign technology.

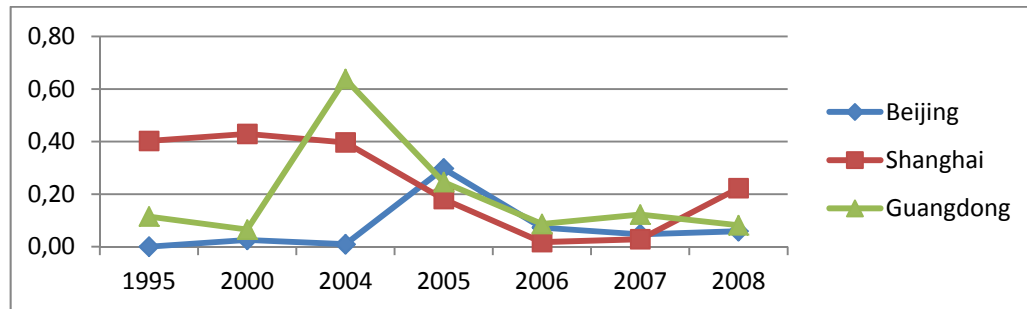
²⁷ Part of the explication may be in the relatively large number of US patents for Biotechnology inventions granted to individuals associated with organizations but who retained the ownership of the patent for their invention. More in depth research would be needed to explore this hypothesis.

²⁸ A study of direct investment in China (Fu, 2008) found that the presence foreign invested firms in coastal regions with R&D activities and abundance of human capital such as in Beijing, Shanghai and Guangdong Province increased regional innovation capabilities and efficiency as well as regional growth.

²⁹ All R&D and foreign technology related data are for the Large and Medium size H-T enterprise only.

Figure 2

Imports of Technology as Percentage of R&D Intramural Expenditures of Large and Medium Size H-T Enterprises in Medical and Pharmaceutical Products Manufacturing



Source: High-Technology Industry Yearbook, 2008, Tables 2-156 and 2-172.

4. Manufacturing of Biopharmaceuticals and Medical Equipment & Appliances

The largest proportion of industrial application of modern bioprocesses is found in manufacturing of medical and pharmaceutical products. This is also the only industry branch for which are available data on the manufacturing of medicines and pharmaceutical products by biotechnological processes³⁰. About three quarters of pharmaceutical products are still manufactured by chemical and traditional Chinese methods. The share of biopharmaceuticals manufactured with biotechnological processes is increasing but still small, about 10 to 15% of all medical and pharmaceutical products.

Applications of biotechnology are also increasingly used in *Manufacturing of Medical Equipment & Appliances*.³¹ Even though many medical equipment and appliances use biotechnology, the actual biotechnological content is variable and not reported. It is likely very high in diagnostic devices and much lower in equipment such as X-ray or magnetic resonance apparatus. To avoid presenting a spurious picture of industrial appli-

³⁰ Manufacturing of biological and biochemical products is a branch of Manufacturing medicines and drugs.

³¹ Even though the statistics on Manufacturing of Medical Equipment and Appliances (MMEA) is included in some Chinese statistics on BT industry, (e.g. China Annual Report on Biotechnology), the share of the BT component in MMEA is largely unknown. The recent reclassification of High-Tech industries has introduced a new class, "Biomedical manufacturing" that includes :

(1) Biopharmaceuticals (2) Traditional Chinese medicine (3) Chemical drugs (4) Artificial organs (5) Medical equipment and appliances manufacturing.

cations of BT, the data for the Manufacturing of Medical Equipment & Appliances are presented separately from the data on manufacturing of bio-pharmaceuticals products.

4.1 Comparison of manufacturing of biomedical products in the three regions

The revenues from sales of biopharmaceutical products manufactured in Guangdong Province were about equal to those manufactured in Shanghai, i.e. about 25% higher than in Beijing until 2008. Then in 2009, Guangdong's province revenues jumped up by 60%, twice as fast as in Shanghai. When available, the more recent (revised) statistics should confirm the leading position of Guangdong's biopharmaceutical sales. As far as the sales of medical equipment and appliances are concerned, the leading position of Guangdong province is unequivocal. Its sales of medical equipment and appliances were 50% higher than in Shanghai and almost twice as large as those by Beijing's medical equipment industry (Figure 3.a and 3.b).

Figure 3a

Sales of Biology and Biochemical Products
(1 000 Yuan (adjusted to constant 2000 prices))

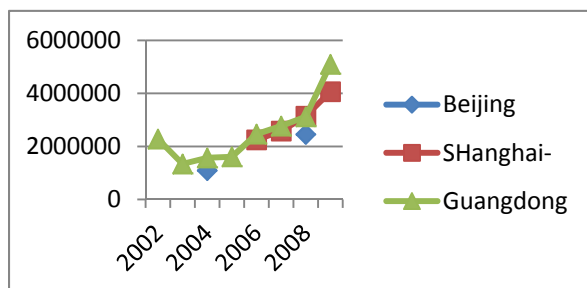
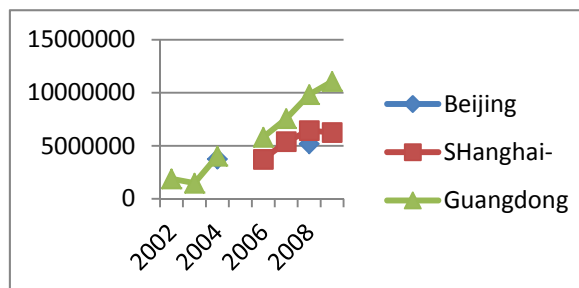


Figure 3b

Sales of Medical Equipment and Appliances
(1 000 Yuan (adjusted to constant 2000 prices))



Sources : Guangdong Statistical Yearbook on Industry, 2010; Beijing Economic Census Yearbook 2004 and 2008 and Shanghai Industrial Development Report - <http://www.sheitc.gov.cn/>

Note: Enterprises over designated size, sales revenues in constant prices (2000=100)

4.2 Biomedical industries³² in Guangdong Province

In this section are presented in more detail the main characteristics of *Manufacturing of biological and biochemical products (biopharmaceuticals)* and *Manufacturing of medical equipment and appliances in Guangdong province*.

4.2.1 Biopharmaceuticals

Industrial production of biopharmaceuticals is still only a small branch of the pharmaceutical industry, which is dominated by manufacturing of chemical and traditional Chinese medicines. However, from 2000 to 2009, the production and sales of the emerging bio-pharmaceutical industry has been growing twice as fast (23.6%/year) as sales of the whole pharmaceutical industry (11.5%/year)³³. Its share of sales of the pharmaceutical industry increased from 5% in 2000 to 12% in 2009.

About eighty percent of pharmaceutical enterprises in Guangdong Province are small. Average employment per enterprise in pharmaceutical industry was 251 persons in 2009. Biopharmaceutical firms are still even smaller, about half the average size of pharmaceutical enterprises. The number of biopharmaceutical firms more tripled from 18 in 2000 to 57 in 2010. As in the leading countries, the established Chinese pharmaceutical firms are increasingly applying biotechnology in their research and production. They are also increasingly acquiring small dedicated biotechnology firms. This trend revealed in trade literature and news is hard to detect in statistics of the pharmaceutical industry.³⁴

The prevailing form of ownership (58%) is “*Chinese-owned private company*”, most of them share-holding, only a small minority of enterprises are listed on stock exchange. The next ownership group are foreign-funded firms (30%). The remaining ten

³² Manufacturing of Medical and Pharmaceutical Products (MMPP) industry includes: Manufacture of Chemical Medicines, Traditional Chinese medicines and Manufacturing of biological and biochemical products (MBBP).

³³ The sources of statistics is the Guangdong Statistical Yearbook, 2010 (Tables 12-26, Table 2-26-1) Main indicators of industrial enterprises (enterprises over designated size, i.e. with annual sales over 5 million Yuan). The average annual growth rates are computed in constant prices (Year 2000 =100).

³⁴ The decline of employment in and sales of Biological and Biochemical segment of the MPPM in 2010 may be the result of mergers and acquisitions rather than an indication of decline of BT applications.

percent are owned by the state.³⁵ The state-owned enterprises are on average almost twice as large as the private ones. Owing to their scale economies and market power, they are also significantly more productive than the small private firms. However, the highest labour productivity and profitability in relation to assets (14.5%) is reported by the foreign-funded firms. This compares with 10% profitability of the SOEs and 11.4% of the privately owned shareholding companies. The foreign funded firms and the private shareholding firms have the dominant shares of industry's sales (40% and 43% respectively).

4.2.2 Manufacturing of medical equipment and devices

In addition to applications of biological rather than chemical processes in manufacture of pharmaceuticals, biotechnology is increasingly used in manufacturing of various medical equipment and devices. Many of these new applications are closely related to information and communication technologies and bio-informatics. The strong specialization of Guangdong in electronics and computer manufacturing explains why revenues from sales of medical equipment and devices exploded almost thirty times from 2000 to 2010, four times as fast as sales of biopharmaceuticals.³⁶ The number of enterprises in the industry more than quintupled. The commercial balance in "Life Sciences Technology" is approximately balanced. Even though exports of Life Sciences Technology are ten times as large as exports of BT products, their share of High and New Technology is still less than one percentage point (0.7%).³⁷

5. Tale of two Cities: Industrial Applications of Biotechnology in Guangzhou and Shenzhen

The comparison of the evolution of biotechnology in the three administrative regions –the three kingdoms- has shown important difference as regards their endowment

³⁵ The other forms of ownership count for about one percent of enterprises (Guandong Statistical Yearbook, 2010).

³⁶ It is practically impossible to estimate the relative importance of the contribution of BT and ICT applications to the fast development of new products and services classified in the statistics on the sales of Medical Equipment, and Appliances (MMEA) which are an increasingly important part (35% in 2010) of the larger industry group 'Manufacture of Medical Equipment, Instruments and Meters' (MMEIM). The source of information on the MMEA industry in the Table 4 is from the Guangdong Statistical Yearbook, 2010.

³⁷ Guangdong Stat. Yearbook, 2010, Table 16-5.

with scientific and academic institutions as well as performance of the industry.³⁸ The present section looks closer at the development of within Guangdong Province, where biotechnology activities are mainly concentrated in two city regions, in and around the capital Guangzhou and the new industrial agglomeration Shenzhen. Owing to their different economic history, Guangzhou and Shenzhen provide interesting cases for the study of transformation and modernization of the industrial space from the traditional to high-technology-based industries (Arvanitis, 2006) and on universities Chen and Kenney (2007). They also illustrate Orsenigo's (2006) conclusion that innovation generates clusters at least as much as clusters create innovation.

Main results of the survey of bio-pharmaceutical firms and research institutes in Guangzhou and Shenzhen in Appendix complement this section.

5.1 The scientific and industrial research infrastructure

5.1.1 Guangzhou

As the cultural and economic center of South China and provincial capital, Guangzhou has a long university tradition. Sun Yat Sen University, one of the top Chinese universities, has been teaching and practicing western medicine from the beginning of the last century.

In view of Guangzhou's rich academic, scientific and industrial infrastructure in pharmaceutical industry and growth potential, it was declared National Biotechnology Base in 2006. Overall, the biotechnology innovating network in Guangzhou includes more than ten universities and colleges, forty research institutes, seventy Key Disciplines above provincial level, five State Key Laboratories, seven national engineering research centers (engineering laboratory) such as Guangzhou Medical Engineering Institute, Guangzhou Institute of Biomedicine and Health Research Institute of Chinese Academy

³⁸ Both Beijing and Shanghai have a provincial status and as such appear alongside the Guangdong Province as 'provinces' in Chinese statistics, the only source of public data available for the comparative analysis.

of Sciences and South China Center for Innovative Pharmaceuticals. These institutions are located in several scientific and innovation parks: Guangzhou Science City, Guangzhou International Biological Island, The Baiyun District Biomedical Health Industry Base and Panyu Biological industry Base. According to the Guangzhou's Statistical Yearbook, number of high-tech enterprises classified in industrial biotechnology increased from 190 in 2008 to 260 in 2010. In contrast, over the same period the number of enterprises in agriculture biotechnology consolidated from 101 to 83.

With its rich medical infrastructure Guangzhou has developed a network of clinical sites. Among the 16 medicine clinical research bases in Guangdong approved by the State, 15 are in Guangzhou. The recently established Guangzhou Biotechnology Outsourcing Union (GZBO), is an industry alliance composed of 30 pharmaceutical & biotech companies, medical service organizations, and scientific research institutions. The annual revenue of biomedical technology services reached about one billion dollars in 2011.³⁹

5.1.2 Shenzhen

Shenzhen's modern industrial development is the result of the economic reform. It transformed the small fishing town into a major city-region manufacturing labor-intensive products mainly for exports. Foreseeing early the necessity to move-up the value-added ladder, the administration established already in 1983 Shenzhen University. Later the Municipal Government and the China Academy of Sciences jointly established Shenzhen Science and Technology Industrial Park in 1985. In 1993 was created Shenzhen Polytechnic, a technical college.

In 1996, the Municipality Shenzhen founded the national level Shenzhen High Technology Industrial Park (SHIP). To further attract SRIs, the municipal government established the Virtual University Campus (VUC). VUC attracted outreach graduate schools of several leading universities. The Beijing's Tsinghua University set up Shen-

³⁹ Guangzhou official investment agency InvestGuangzhou (2012) , *Bio-pharmaceutical Industry in 2011* (24/4/2012) (<http://www.investguangzhou.gov.cn>)

zhen Tsinghua Graduate Research Institute in the Park in the 90s, followed by research bases of Beijing University, Chinese Academy of Engineering and Shenzhen Graduate School of Harbin Institute of Technology established in 2002. The early educational and scientific infrastructure was built in support of the engineering, electronic and ICT industries that concentrated in Shenzhen. Most of these institutions are geared to training of specialists for electronics, information and telecommunication technology and medical equipment & devices industry. The Institute of Biomedical and Health Engineering is one of the key research divisions of the Shenzhen Institute of Advanced Technology, founded by joint effort of the municipal government, the Chinese Academy of Sciences and the Chinese University of Hong Kong.

After becoming member of Shenzhen VUC in 2000, the City University of Hong Kong established in 2007 City University Shenzhen Biotech and Health Center specialized in biochip technology and nano-biotechnology. The latest academic newcomer to Shenzhen, officially established in 2012, is the South University of Technology (SUSTC) a public institution funded by the municipal government of Shenzhen and accredited by the Ministry of Education.⁴⁰ Thus in Shenzhen the research and academic infrastructure was attracted by and created on the behest of the nascent innovation clusters first in ICT but also in bio- and nano-technology rather than acting as an attraction of industrial enterprises

5.2 Industrial R&D

5.2.1 Guangzhou

According to the report on the Guangzhou National Base of Bio-industry, there were about 300 bio-technology enterprises in 2006, 75% in the domain of biopharmaceu-

⁴⁰ The **SUSTC** has a wide range of programs, including *Neural and Cognitive Sciences, Biology and Gene Engineering, Nanoscience and Nanotechnology, Mathematics and Applied Mathematics, Large-Scale Computational Research, Robotics and Artificial Intelligence, Information Systems and Electronic Engineering related to research and development of biotechnology and medical equipment & devices. The teaching is in English or Mandarin, according to instructors' choice. The recruitment of the faculty is international.*

ticals, the remaining 25% active in bio-agriculture, food and environmental protection. The total R&D employment in five major national R&D Centers (Chen, 2008) and further ten local centers is estimated to be about 7 000 persons. The intensity of R&D expenditures is estimated to be in the range of 3-5% of sales. However, the search for recent statistical information on Guangzhou bio-industry and its R&D activities has not been very successful.⁴¹ Since biotechnology is one of the strategic industries of Guangzhou municipality's 12th 5-year plan, the lack of statistical information on BT is disturbing.

Pursuing the cluster-based development strategy, the Guangzhou municipality built recently several Scientific and High Technology Industrial parks. The Science City with Guangzhou Institute of Biomedicine and Health of the CAS , Guangzhou International Biological Island built at the cost of \$387 million, opened in July 2011 (see also Anonym, 2009) . The park is offering incentives such as an annual science and technology fund of up to 300 million RMB (\$46 million) for "outstanding science and technology projects within the district" as well as R&D, housing and training subsidies. Other new projects that offer infrastructure and services for biotech firms are the Health Industry Development Base of Guangzhou, the Higher Education Mega Center, Guangzhou Baiun Biological Port, Baidi biotechnology Industrial Park, Gaotang Industrial Estate and Guangzhou Marine Industry Park.

The growing personal income in China and the extension of the health care insurance to 90% of Chinese population for which the Chinese government earmarked \$125 billion in the stimulus bill (Nature Biotechnology, 2011) will continue to generate demand for R&D-based modern biopharmaceutical products, medical equipment and procedures for many years to come.⁴² At present there is not enough information on industry biotechnology-related R&D in Guangzhou.

⁴¹ The forward looking planning documents published by "Invest Guangzhou", the investment promotion agency contain little up-to- date information on the state of the industry.

⁴² This in addition to the Mega New Drug Development Program which allocated \$12 billion for the 2009-2020, that provides grants for up to \$200 million to homegrown drug development.

5.2.2 Shenzhen

In comparison with Guangzhou National Base of Bio-industry there is more information on the Shenzhen National Bio-industry Base (Anonym, 2009). The R&D expenditures have increased by an annual inflation-adjusted rate of about 45% from 0.25 billion Yuan 2005 to 1.08 billion Yuan in 2007 and dropped to 0.88 in 2008, the first year of the global crisis. Computations presented in Table 5 using the numbers in the Annual Report on Biotechnology in China suggest that the research intensity of enterprises in biotechnology and medical equipment industries,⁴³ i.e. R&D expenditures/Sales, doubled from 1.2% in 2005 to about 2.5% in 2008. During the same period the number of patent applications jumped from 175 to 1380 and the number of patent granted from 52 to 653.⁴⁴ This information probably does not yet include activities of BGI Shenzhen (see the box below). Most of the R&D in Shenzhen is conducted and financed by industry, respectively 90% and 80% of the total R&D expenditure (Chen and Kenney, 2007).⁴⁵

Table 5
Innovation activities and results, Shenzhen

	2005	2006	2007	2008
R&D expenditures (100 millic	2,5	3.3	10,8	8,8
R&D/Sales	1,2%	1,3%	3,1%	2,5%
No. of pat. applications	175	250	1278	1380
Number of patents awarded	52	56	223	653

Source: Annual Report on Biotechnology in China, 2009, Shenzhen National Bioindustry Base

Both Shenzhen and Guangzhou demonstrate increasing scientific research performance. According to the latest Nature Publishing index 2012, Shenzhen BGI moved in the 1st place among Chinese institutions that have published in Nature Biotechnology Journal (and to the 2nd in Nature Genetics and 5th in Nature). Guangzhou Sun Yat-sen University climbed in the 16th place.

⁴³ They are aggregated in the chapter on Shenzhen in the Annual Report on BiotechnologyBT in China, 2009, p. 329-335.

⁴⁴ It is not indicated whether these are invention patents.

⁴⁵ All industrial sectors in 2004.

5.3 Industrial production using modern biotechnology

The documents from the Guangzhou and Shenzhen municipal statistical offices use the new statistical classification of High-Technology products introduced by China Statistical Office in 2006.⁴⁶ Three classes include applications of modern (high-tech) biotechnology, the first in agriculture, the second in industry and the third in services. The class “Biopharmaceutical products and medical devices” is much larger than its name suggests. In addition to bio-pharmaceuticals it includes also traditional Chinese medicines, chemical drugs, artificial organs and medical equipment & devices.⁴⁷ The combined sales reached in Guangzhou 26.8 billion Yuan in 2009⁴⁸ and 28.4 in Shenzhen in 2008 (see Figure 4.).

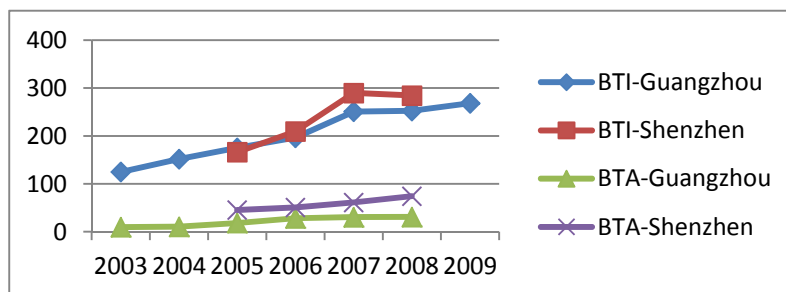
Applications of biotechnology in agriculture accounted for about 5% of the whole BT industry in Guangzhou, less than in Shenzhen (20%). Even though biotechnology services are provided by many firms, the statistics on bio-services both in Guangzhou and Shenzhen are not yet available.

⁴⁶ China Statistical Office (2006)

⁴⁷ The composition of the category” Biopharmaceuticals and medical equipment” according to the 2006 China's high-tech product catalog <http://www.cskj.gov.cn/doc/2008/3.htm> 《中国高新技术产品目录》（2006年）

⁴⁸ Sales in Guangzhou continued to climb, reaching 46.6 billion yuan in 2010. Corresponding data for Shenzhen not yet available (Guangzhou Statistical Year Book, 2012).

Figure 4
Sales of High-technology Biotechnology Production
by Industrial and Agricultural Enterprises
in Guangzhou and Shenzhen (100 million Yuan)



Sources: Guangzhou: Guangzhou Statistical Yearbook, 2004-2010;
Shenzhen: Author's computation data from the Annual Report on China
Biotechnology, 2009
Notes: BTI- Biotechnology production by industrial enterprises;
BTA- Biotechnology production by agricultural enterprises

5.3.1 Guangzhou

Guangzhou is China's leading center of pharmaceutical industry and a major source of Chinese herbal medicine. In addition to traditional pharmaceutical firms, a growing number of dedicated biotech firms are developing new drugs and diagnostic methods, medical equipment and devices based on modern biotechnology and genetic engineering.

The leading pharmaceutical group is Guangzhou Pharmaceutical Holdings Ltd. (GPH) manufactures a number of patented medicines. One of its subsidiaries, Hanfang Pharmaceutical Company Ltd, active in modern Chinese medicine, is among the most active research oriented Guangdong pharmaceutical companies.

Techpool Biopharma Ltd is a biopharmaceutical firm noted for its intensive patenting activity (19 applications in China and 6 granted. It is one of the most research oriented Guangzhou biopharmaceutical firms (see BOX 1). Another important manufacturer is Grandhope Biotech established by overseas Chinese scientists and entrepreneurs. It manufactures bio-prostheses, for which it owns 4 US and 11 Chinese patents. Spin-offs from Sun Yat Sen University include: Guangzhou Double Bioproduct Co. that developed four new cancer drugs, based on inventions with more than 10 patents pending. Another

well-established spin-offs is Da An Gene Co., specialized in molecular and in-vitro diagnostic products, protected by several patents.

Several big multi-national companies have invested in Guangzhou, such as Alliance BMP Ltd, American Baxter, Hutchison Whampoa Limited and most recently the Swedish Nycomed. However, none of them has headquarters in Guangzhou.

Guangzhou is one of China's most important distribution centers for medicine and medical supplies. It is also a major medicine export base and the largest market and distributing center for Chinese traditional medicine. The logistic center of Sinopharm Medicine Holding Guangzhou Corporation, founded in 2009, draws dealers and buyers from South China, Hong Kong, Macao and Southeast Asia.

Box 1.

Guangzhou Techpool Bio-Pharma

Guangdong Techpool Bio-Pharma, located in Guangzhou Gaotang Industrial Estate, is one of China's leading biotechnological firms, ranked 17th in the category of Recombinant and MA therapeutic manufactures of the Top 60 biopharmaceutical Manufactures in China (Bioplan, 2008). It was founded by Dr. Heliang Fu in 1993. Dr Fu received his PhD in biochemistry from Nanjing University. His experience with the doctoral research project for the National High Technology Research and Development Program of China (863 program) led him to give up the opportunity to study at Harvard. Instead he started his own company at the age of 33.

Since its establishment, Techpool has pursued R&D, product innovation (protected by 5 Chinese invention patents) and high standard manufacturing. The first product Luoxin ® (Urokinase for injection), based on dr. Fu's patented results of doctoral research was launched in 1994. A new joint-venture subsidiary was launched in Hong Kong in 1997. The following year the company built a new facility at its present site. The production facility received the certificate of Good Manufacturing Practices (GMP) by the State Food and Drug Administration (SFDA), an indispensable warranty of strict quality standards and documentation system to guarantee the quality and traceability of its products. Techpool obtained the Innovation Prize of Private Technology enterprise of PRC in 2001. The company was restructured in 2004 and the Shanghai Industrial Pharmaceutical Investment Company Ltd. became the controlling shareholder in the same year.

According to Bioplan (2008), Techpool is the leading manufacturer of human urine –sourced protein in China. Its portfolio includes compounds used in the treatment of stroke and multiple organ dysfunctions. Its products are sold all across China except Tibet by 29 sales branches and exported to the US, UK, Switzerland, Germany, Italy, France and other countries. To manage its growing exports, Techpool established Guangdong Techpool Overseas Pharmaceutical C. Ltd in 2005.

Techpool's R&D and innovation are fully focused on biotechnology. Its R&D expenditures were about 4% of sales revenue in 2008/9. The government was the principal source of the capital funding for R&D, production and commercialization. Its patent chest contains 16 invention patents awarded by the China patent office and 14 patent pending, as well as one USPTO patent and 5 patents pending. To further develop future research, the company started the Techpool Protein Therapeutic Technology Research Center in 2006. It also set up a collaborative laboratory with Fudan University (Shanghai). To tap expertise from Hong Kong it founded Techpool Research Institute in HK and Collaboration agreement with Austarpharma. In the same year Techpool teamed with SCI in the U.S. for obtaining FDA certification. In 2010 the Swiss biopharma Nycomed based in Zurich, acquired the majority 51.3% stake in Guangdong Techpool Bio-Pharma.⁴⁹

⁴⁹ Nycomed, the 28th largest biopharma in the world, generates the highest proportion of its revenues from developing countries of any large or medium-sized global pharmaceutical company. Its largest market is

Techpool's employment grew from 370 in 2004 to more than 530 in 2009 and at the same time its total revenue increased from 157 million Yuan to more than 350 million Yuan in 2008 and more than 440 in 2009.

The principal knowledge development strategies pursued recently by Techpool are focused on enlarging the product chain, increase investment and accelerate R&D and commercial brand building. The sales strategy in China is focused on building up own sales team and develop a network of endpoint merchants. Its marriage with Nycomed is a good example of Matthews' (2002) leveraging strategy of latecomer firms.

5.3.2 Shenzhen

In contrast to Guangzhou specialized in biopharmaceuticals, the largest component of bio-industry in Shenzhen is manufacturing of medical equipment and devices, accounting for almost half (47%) of Shenzhen's bio-industry sales in 2008 (Table 6). Shenzhen area is China's prime producer of medical equipment and devices, with about two thirds of national bioengineering projects.

Table 6
Composition of the bio-industry, Shenzhen, 2008 (%)

	2005	2006	2007	2008
Biomedical	48,3	53,0	49,9	47,0
Biopharmaceutical	25,6	21,6	23,4	22,0
Bio-agricultural	21,4	19,5	17,0	20,7
Bio-environment	4,7	5,7	9,4	10,1
Biological manufacturing	0	0	0,03	0,02
Biological service	0	0	0,14	0,14
Bioenergy	0	0	0	0

Source: Annual Report on Biotechnology in China, 2009

Among key enterprises in the bio-medical industry are: Shenzhen PIJI Biological Engineering Co. Ltd the manufacturer of in vitro diagnostic equipment, Snibe Co.Ltd, the leading Chinese leading company in the field of immunoassay systems and Mindray, the developer, manufacturer and exporter of medical devices for patient monitoring, diagnostics and ultrasound imaging systems. Enterprises in this industry are feeding on Shenzhen

Russia, followed by Brazil. China was not included in its top five revenue producers. Nycomed took a big step toward redressing its China underperformance by spending \$210 million to buy a 51% stake in Guangdong Techpool Bio-Pharma (Biotoday, 2011, April 8).

area's strong specialization in research and manufacturing of electronics, communication and information goods & equipment.

The recent establishment of BGI, the former Beijing Genomics Institute (see details in the Box 2) has given Shenzhen a world leading position in genomic sequencing. Shenzhen Yishentang Biological Products Co. Ltd has brought to market HCV Antibody protein chip detection kit (granted type A New Drug certificate by the SFDA) and HBV drug resistance gene chip detection kit, which the company co-developed with the Academy of Science for Military Medicine.

The biopharmaceutical industry is the second largest segment of the BT industry. The leading enterprises are Neptunus, Essex Biotechnology, Sinovac, Contax and, Shenzhen Essex Biotechnology, and WeiWu Guangming Huasheng Yuan. Neptunus-Interlong is a wholly Chinese-owned publically listed biopharmaceutical company, engaged in R&D and producing vaccines against infectious diseases. It was founded in 1994 under the name Shenzhen Interlong Biotech Co., one of the earliest producers of the recombinant human interferon and injectable interleukin-2 in China.

The emergence and evolution of biotechnological clusters in Guangzhou and Shenzhen provide each a persuasive empirical support for Orsenigo's (2006) conclusion of the cluster literature survey: "...innovation generates clusters at least as clusters create innovation". Guangzhou universities, especially *Sun Yat Sen University*, the top Chinese patentee in biotechnology, and research institutes offered the necessary scientific infrastructure and appear to have successfully played the role of anchor-tenants attracting a growing number of biotechnology firms to Guangzhou's National Base⁵⁰ of Bioindustry's science parks. Thus Guangzhou cluster is a typical example of a cluster "creating" innovation. Shenzhen appears to be an archetype of the "innovation generates clusters" kind of process, first in ICT followed by biomedical technologies. The combination of biotechnology with informatics explains the growing size and performance of medical

⁵⁰ The designation "*National Base*", i.e. *national level* science park is an official recognition of the scientific excellence. Incentives associated with this designation have an attraction power of its own. According to Cheng et al. (2013) empirical study, scientific parks of that level attract high-tech R&D-intensive enterprises; scientific parks of a lower hierarchical rank (provincial, municipal) are typically agglomerations of non-high tech enterprises engaged in production rather than in innovative activities.

equipment & devices manufacturing and bioinformatics within the Shenzhen cluster. It illustrates Porter's (1998) emphasis on complementary industries in successful clusters.

BOX 2. BGI-Shenzhen

China's is the only developing country that joined the international Human Genom Project and successfully sequenced one percent of the human genome. The sequencing was performed by the Beijing Genomics Institute (BGI), a start-up company founded in 1999 by returnees holding academic positions in Denmark and the US, supported by a seed money grant of 1 million Yuan and a building from the CAS and the government grant of 3 million Yuan for the Human genome project.

After the project was completed BGI had the sequencing equipment and 150 competent technicians but no further funding. The company moved to Hangzhou in exchange for funding from the local government for a series of practical applications with Chinese partners such as the sequencing of the Rice genome (2002) which became a cover story in *Science* (2002)⁵¹ and the SARS virus, including creation of a detection kit, in 2003. As a result, BGI became part of the CAS with more stable funding. Further projects followed,⁵² including the sequencing of the genome of the Domesticated Silkworms and, just in time for the 2008 Olympics, the genome of the giant panda bear, the mascot of the Beijing games.⁵³ BGI's scientific production is impressive. It has been ranked 4th among the top 10 Institutions in Nature Publishing Index for China 2010. But the CAS administrative oversight and restrictions did not fit BGI's goal to become an independent specialized Genome sequencing operator.

The next move of BGI was to Shenzhen in 2007 where it was lured by the municipal government's offer of 10 million Yuan start-up fees and 20 million Yuan annual grants for 4 years and freedom from Beijing's interventionist oversight. As the BGI's chairman Yang is reported to say, "In Shenzhen the mountains are high and the emperor is far away" (Nature, 2010). Following the Government policy of supporting biotechnology development, China state-owned Development Bank extended to BGI a 10 billion Yuan loan for ten years in 2010. BGI used the loan to acquire 128 latest models of Illumina 2000 sequencers and 27 units of SOLID 4 systems. BGI claims that its sequencing capacity is larger than the combined capacity of the US and it can sequence more economically than anyone else.

To be able to service its huge debt and to complement its strength in bioinformatics with up-to-date related scientific competencies, BGI has made acquisitions and entered scientific partnership with researchers and laboratories from all over the world. It has established affiliates in the US, *BGI Americas*, headquartered in Cambridge, MA, and *BGI Europe*, headquartered in Copenhagen, Denmark to be close to potential partners and customers. It also announced **building a next generation sequencing facility in Singapore**. The best evidence of this outward oriented partnership-based strategy is that most of the new equipment (100 gene-sequencers) are installed in the Innovation Institute of Trans-omics in Hong Kong, a joint venture between BGI and the Chinese Honk Kong University, with a strong scientific base in genomics, proteomics and related biomedical disciplines. Another reason for locating the bulk sequencing capacity in Hong Kong is its stable legal system and international character connctions. This is not the first joint project between Shenzhen and the neighboring Hong Kong. The CUHK has opened the wholly-owned Shenzhen Research Institute in Shenzhen's Virtual University Park in January 2011. GBI research activities translated in an increasing flow of scientific publications. GBI ranked first among Chinese institutions on the *Nature Biotechnology publishing index* in 2012.

In March 2013 BGI completed acquisition of *Complete Genomics* of California. Its new research divisions BGI Tech and BGI Healthcare are employing one thousand staff each and BGI agriculture divisions with 500 employees are extending BGI operations in commercial activities.

The list of recent initiatives and development of BGI activities is too long to be resumed here. A single number resumes the rate of change. To cope with the expansion of BGI activities the number of its employees jumped from 1500 in 2010 to 4000 at the end of 2012. For more details on the explosive expansion of GBI's activities see Cyranoski (2012), published in *Nature Biotechnology* in December 2012.

⁵¹ [A draft sequence of the rice genome \(*Oryza sativa* L. ssp. *indica*\)](#). *Science*. 2002 Apr 5; 296(5565):79-92. by Yu J, Hu S, Wang J, Wong GK, Li S, Liu B, Deng Y, Dai L, Zhou Y, Zhang X, Cao M, Liu J, Sun J, Tang J, Chen Y.

⁵² See http://en.wikipedia.org/wiki/Beijing_Genomics_Institute).

⁵³ The many scientifically more important recent achievements of the Shenzhen BGI is too long to reproduce here (for details see: Shenzhen BGI, accessed 2012-7-4

6. How important is the contribution of biotechnology to the transformation of Guangdong's industrial structure into high-tech, high value-added export base?

Finally, it is possible to assess whether the biotechnology is becoming one of the high-value added industries replacing Guangdong's traditional, labour-intensive industries. How does the growth of BT industry compare with the performance of traditional and other high-tech industries in Guangdong?

A perusal of Table 7 shows *Nine Major* manufacturing industries classified in three groups, their average inflation adjusted real annual growth rate from 2000 to 2010 and their share of the output value of the nine industries at the beginning and the end of the period. The annual growth rate of output of the three *Potential industries* which include medicines from 2000 to 2010 was 17.3%/year, faster than that of "Traditional industries" (12.7%/year). The output of biopharmaceuticals increased slightly faster (18.9%/year) and medical equipment and devices even faster (30.24 %/year).

Table 7
Annual Growth Rate and Shares of the Gross Industrial Output Value, Nine Major Industries, Guangdong Province, 2000-2010

	Average annual real growth rate 2000 - 2010	Share 2000 (%)	Share 2010 (%)
Industrial enterprises above designated size	16.6	100.0	100.0
Nine Major industries	16.3	71.5	69.6
Three Fresh Industries (100 million yuan)	17.3	Share in nine major industries	
		60.5	65.8
Electronic and Information technology	18.3	27.1	32.2
Electric Equipment and Special-purpose Machinery	17.6	18.2	20.5
Petroleum and Chemistry	14.7	15.2	13.2
Three Traditional Industries (100 million yuan)	12.7%	29.6	21.6
Textile and Garments	10.9	13.7	8.6
Food and Beverage	12.7	8.9	6.5
Building Materials	15.6	6.9	6.5
Three Potential Industries (100 million yuan)	17.3	9.9	12.5
Logging and Papermaking	14.4	4.3	3.7
Medicine	11,4	2,1	1.3
Biopharmaceuticals	18.9	0.11	0.24
Medical equipment & devices	30.2	0.08	0.36
Motor Vehicles and Motorcycles	25,6	3,47	7.5

Source: Authors' computation-data from Guangdong Stat. Yearbook, 2009 and 2011, Tables 12-01 & 12-26

Note. In contrast to T12-01 of the Guangdong Stat. yearbook where the growth rates are in current prices, the rate in the table above are in real terms, using constant prices 2000

Thus both main industrial users of modern biotechnological processes, manufacturing of biopharmaceuticals and medical equipment and devices taken together, recorded annual growth between 20 and 30%/year⁵⁴, faster than 17.3%/year reported by the three *Fresh industries*, but probably slightly slower than the motor vehicles and motorcycles (25.6%). Even though it increased significantly from 2000, the output share of biopharmaceuticals and medical equipment & devices relative to *Nine Major industries* is still well below one percentage point in 2010. Even if all pharmaceutical products were produced by biological and biochemical methods,⁵⁵ which is yet unlikely to happen for many

⁵⁴ The exact content of BT use in manufacturing of “Medical equipment and devices” is unknown; hence the combined growth rate of those two industry segments is likely to be between 20 and 30%/year.

⁵⁵ Today, about 25% of new drugs are produced by biotechnological processes.

years, their share of total industrial production at today's level would still be only slightly more than one percent. Thus contribution of BT to industrial transformation is likely to remain marginal for some time.

7. Discussion and Conclusion

7.1 The romance of three Kingdoms

The overview of the post-reform Chinese scientific research and innovation system shows that scientific research is still extremely centralized in Beijing. The capital has also a high share of regional headquarters of pharmaceutical multinational firms, many attracted by the rich scientific infrastructure and seeming abundance of competent low-cost research personnel. These advantages have recently led many of big international pharmaceutical firms to change their business model, cutting on research activities in the U.S. and EU and outsourcing research and clinical trials to China and other emerging countries.⁵⁶ Owing to the high concentration of scientific research institutes and universities' spin-offs firms located in well-known scientific and research parks, research institutions and industry in Beijing are benefiting from the new strategy of foreign multinationals.

In comparison to Beijing and to a lesser degree to Shanghai, Guangdong's scientific infrastructure in SRIs is poor. In view of this polarization it is surprising that in terms of the number of scientific publications in biotechnology, Guangdong's is not lagging more behind Beijing and Shanghai. On the other hand, the volume of R&D resources engaged in Guangdong's large number of enterprises manufacturing medicines & pharmaceuticals and medical equipment & appliances is larger than in the two other city-regions. Our survey shows that the first strategic goal of the large majority of Guangdong's firms is to increase and improve their R&D, supporting the survey results suggesting that Guangdong companies understand the importance of R&D for learning and innovation.

⁵⁶ See *Nature Biotechnology*, vol. 29, (4), 299

Based on our simple bibliometric analysis⁵⁷, it appears that even though collaboration between researchers and industry is low in all three regions, enterprises in Guangdong province are co-coauthoring scientific articles with university researchers more frequently than those in Beijing or Shanghai.

Patenting biotechnology inventions in China is dominated by universities. Two Guangzhou universities with a total of 150 patents are among the top 10 Chinese patentees, not far behind the two Shanghai universities (195 patents) and ahead of Beijing University (the only one that made the top 10 with 65 patents). The more important comparison is, however, the number of US patents where the Guangdong organizations are trailing behind those from Shanghai and Beijing.⁵⁸

Production of medicines and pharmaceutical products by Guangdong's industry is superior to that of Beijing and Shanghai. At the time of writing, the 2009 data suggest that biopharmaceutical sales of Guangdong were ahead of Shanghai's by a margin of about 25%. According to another estimate, the combined production of the bio-industrial bases of GP (Guangzhou and Shenzhen) lead was even larger in 2007.⁵⁹ The numbers suggest that despite being neglected by the Central Government's scientific policy, BT manufacturing firms in Guangdong province are competitive with the two better known BT clusters in Shanghai and Beijing. The entrepreneurial culture of the Pearl River Delta appears to be succeeding to create a biotechnology production cluster while the other two regions, especially Beijing are more focused on research. Their innovative products and processes are less or not yet as successful in the market place as those from Guangdong.

⁵⁷ Note that the analysis reported here is limited to articles published in Chinese. Validation of our results by an analysis of articles published in foreign journals was beyond our means.

⁵⁸ A relatively large number of US patents for BT inventions is being awarded to Chinese individuals. They are not taken into account in our statistics. A more in-depth analysis could reveal that many of them are among the returnees who founded start-up companies using their own patented inventions.

⁵⁹ Note that according to the National Development and Reform Commission High-Tech Industry Department data for January-October 2007, the combined production value of Guangzhou and Shenzhen's bio-industrial bases was significantly larger (22.5+26.6 49.1 Yuan billions) than that of Shanghai's (29.3 Yuan billions) and Beijing's (19,2) (Zhang et al., 2011, Table 7).

7.2 The tale of two cities

The history of the bio-clusters in Guangzhou and in Shenzhen provides an interesting contrast. The university research infrastructure, large pharmaceutical industry, and to lesser degree scientific research institutes existed in Guangzhou before biotechnology-oriented firms and research labs emerged in the city-region. Several successful spinoffs from Sun Yat Sen University and other institutions, private firms, joint ventures and foreign invested firms agglomerated in and around the city, mostly attracted to one of several scientific research and technology parks established by the provincial and municipal governments.⁶⁰ The cluster (according to Chinese interpretation) received the seal of approval from the central government's decision to recognize it as a National Biotechnology base in 2006, at the same time as Beijing and Shanghai. The recognition opened the door to additional government support for biotechnology development. In addition to incentives and advantages provided by the three levels of government to enterprises and research institutes located in scientific parks, they benefit from various agglomeration economies. The growth of the number of new BT enterprises and research organizations in and around Guangzhou appears to be evolving into a nascent innovation cluster according to the conventional model (Pre-existing scientific and education infrastructure spinning off and attracting new enterprises in the innovating space).

However, up to now there are few signs that enterprises and organizations collocated in scientific parks and development zones constitute a “buzzing” network of social relationships creating an entrepreneurial climate where knowledge spillovers contribute to self-sustaining innovation-based growth. If anything, it appears that the collaborations of the leading firms are more active with their foreign and out-of province partners than with the firms in the same Scientific or Technology Park.

The situation in Shenzhen appears to be the result of an opposite causation. In the first years of Shenzhen's industrial awakening, there was practically no local scientific or technological infrastructure. The innovators, i.e. the first privately-run MKE firms which

⁶⁰ The spatial agglomeration of BT research facilities and firms is benefiting from the local governments that are acting as a good mother in law, being supportive but not overly interventionist (Segal, 2003).

introduced industrial production in the hitherto little fishing town and municipal government recognized the need for local technological and higher education institutions to attract, train, in order to retain qualified manpower (Chen and Kenney, 2007). So, in collaboration with an understanding local administration which owing to Shenzhen's special economic zone status has relatively free hands and government support, they created academic and research institutions by attracting qualified personnel and later outreach spin-off of several leading Chinese universities and technological institutes.

The history of biotechnology development in Shenzhen seems again to follow this pattern. The first biotech company Kexing Biotech was founded in Shenzhen in 1989, followed by Wastin Genetech Co. in 1997 and SiBiono GeneTech in 1998. SiBiono, founded by a returnee, Dr. Peng (PhD Chiba University in Japan and postdoctoral research at University of California in Los Angeles) successfully developed and commercialized the first cancer gene therapy in the world (Bioplan, 2007). Other start-up biotech firms were attracted by the successful pioneers.

More recently, the opportunistic acquisition of the Beijing Genomic Institute is again an innovation that attracts rather than follows other cluster players. In this case, it is more complicated since the BGI is in Shenzhen, but the company has installed the huge sequencing capacity beyond the borders in Hong Kong, thus de facto integrating Hong Kong's more advanced biotechnology knowledge infrastructure with its advanced specialized human resources and wide international contacts. Installing 127 gene sequencers, the largest sequencing capacity in the world in Hong Kong's liberal economy far from Beijing's Central government's red tape⁶¹ and unpredictable political and economic events, acts as insurance and is helping BGI-Shenzhen's to create research partnerships all over the world. By providing sequencing services BGI-Shenzhen is recouping the huge investment in the sequencing capacity and learning in the process. It became within the short five years the most prolific Chinese contributor of scientific articles to the prestigious Nature Biotechnology journal. It created an impressive network of partnerships

⁶¹ It is however hard to believe that China's government did not have more than a helping hand in this scheme.

with leading organizations in the field of genomic sequencing and lately it launched several commercial subsidiaries with important financial participation from foreign partners.

It is too soon to judge whether the spatial agglomerations of BT organizations in Guangzhou and Shenzhen will grow into a full-fledged innovation clusters with the inner dynamics creating knowledge spillovers and other manifestations of a successful regional innovation system. The potential is there, especially in the light of the increasing collaboration and integration with Hong Kong universities and research institutes. Hong Kong entrepreneurs and policy makers eagerly pursue the strategy to turn Hong Kong into PR China's window to the larger world.⁶²

In an effort to speed the industrial transformation and upgrading, Guangzhou turned to Singapore. It launched in collaboration with Singapore the project the Sino-Singapore Knowledge City, leveraging in Singapore's experience in developing emerging industries of knowledge-based economy integrated with modern community services. Life and health sciences are among the main new sectors included in the project.⁶³

7.3 Contribution of biotechnology-based manufacturing to upgrading Guangdong's economic structure

Over the last decade pharmaceutical industry as a whole has not grown faster than the group of traditional industries. However, the bio-pharmaceutical branch of the industry did much better, reporting a 19% increase in inflation adjusted production output and the industry manufacturing medical equipment & devices en more so.

Many products classified in "Manufacturing of medical equipment and devices" are combining biotechnology with electronics, information & communication and instrument technologies. Production and innovation clusters in electronics and ICT are already well established in Guangdong,, especially in Shenzhen The complementarity with

⁶² This strategy was mentioned by several interviewees in the early stage of our survey in Hong Kong. Critics of Hong Kong's 'laissez-faire' approach to industrial development point-out that the development in Hong Kong compares poorly with the more interventionist policy of Singapore (Baark, 2005, Tsui-Auch, 1999).

⁶³ Invest Guangzhou, (24/08/2011).

health sciences and biotechnology is undoubtedly a source of agglomeration and knowledge externalities contributing to the very fast growth of medical equipment and devices manufacturing. However, impressive as it is, the share of both health-sciences related “potential” industries is still less than one percent.⁶⁴ Thus even at the fast current rate of growth, their contribution to the high-tech/high value-added modern sector remains marginal. BT-based industries will need several years of rapid development to become significant players in the new high-tech sector. However, this does not in any way reduce the growing importance of their contribution to satisfaction of the increasing demand of the Chinese-agriculture, environment and health system.

Meanwhile it appears that the real alternative to the traditional labour-intensive industries comes from manufacturing of motor vehicles and motorcycles, another designated “Potential” industry. It has been growing much faster than any other large industry and its share of manufacturing sector is rapidly catching -up with the production of textiles & garments. Thus it appears that for the foreseeable future, the modification of the industrial structure is likely to follow the more traditional path.

Shortcomings and future research

An important part of biotechnology research and applications in the three clusters takes place in agriculture. Owing to data and space limitations it could not be treated in this paper. It is unfortunate that the otherwise unique and very interesting publically accessible Chinese statistics on manufacturing industry, high-tech firms and science and technology activities are mutually incompatible. Furthermore, information on new industries at the provincial level such as biotechnology and medical equipment and devices is limited, so is the information on small HT firms, the hotbed of innovation. The lack of access to micro-data on biotechnology firms made it impossible to test the hypothesis that companies located in high-tech and scientific parks are more successful than those not located there.

⁶⁴ Note that the life sciences-based services such as contract research, clinical tests, diagnostic services etc. are not included in the present study for lack of statistical information. Their contribution to modernization of Guangdong’s economic structure is recognized but not yet taken into account. It is likely to be growing even faster than biotechnology related manufacturing activities.

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9. Appendix

Results from the Survey of BT firms and research laboratories in Guangdong province

The objective of the survey was to find basic facts about the origin, activities, strategies and challenges faced by organizations, i.e. research institutes and specialized firms using modern biotechnologies in Guangdong Province, more specifically in Guangzhou and Shenzhen. After interviewing several leading scientists in academic and public research institutes in Guangzhou, followed interviews with executives of about fifty presumably biotechnology dedicated firms. Given the limited resources available for the survey and the difficulties encountered in establishing the population of what could be considered dedicated biotechnology firms, as well as problems obtaining interviews, we consider the results illustrative rather than representative.¹

The main findings show that like in the U.S. and Europe, more than 80% of firms are small (according to the Chinese criteria) employing less than 300 persons. Private ownership¹ is dominant. Their main activities are R&D and manufacturing. One in five enterprises is a spinoff, mostly from universities or hospitals, but also some from government institutions and other firms. Only about one in five firms are foreign-controlled or joint ventures.

Ten firms, of the total of 31 who responded the question, were founded by entrepreneurs from other industries and seven by former executives from a State-owned enterprise. Returnees founded six and former researchers five companies. Thus entrepreneurial and managerial experience and established contacts with municipal and provincial administration and financial institutions seem to be as, or more, important than the scientific and technical background or foreign experience.

1. Qualified scientific, engineering, and managerial manpower

The fast growth of BT in the region is reflected in the tight labor market, especially for the highly qualified manpower. Almost half of the interviewed firms report unfilled positions, mainly in the direction of R&D, management, finance and marketing. The long gestation of research projects, their high cost and uncertain results encourage promising graduates to go study abroad or accept employment in foreign firms rather than seek jobs in small start-up firms. Many firms find it difficult to hire competent personnel capable of doing innovative research.

2. Research and development

To understand, acquire and use modern, large molecules-based bio-processes, enterprises have no choice but to engage in R&D as part of their learning process. According to our interviews with researchers, most enterprises are still lacking the R&D culture and investment in new technologies is slow and insufficient, information confirmed by the statistics showing that only about 40% of firms engage in R&D activities. The preferred strategy for the survival and growth of existing enterprises as well as for the new entrants is focused on downstream R&D, the creation of new products and market niches for the national and, increasingly, the export market.

The median R&D intensity of the 33 enterprises that responded the question is 5-10% of sales which seems realistic, given that most firms are small and their R&D expenditures are higher relative to their sales than in larger firms that can spread R&D expenditures over larger sales revenues.¹ There is no statistically significant relationship between the R&D intensity and the size of the firm, nor between the type of ownership and R&D intensity. However, firms established by returnees are more likely to spend more on R&D/Sales than those founded by entrepreneurs from other industries.¹

Table 4
R&D/Sales by type of Founder (%)

Founder category	< 5	5-10	11-25	26-50	Total
Former researcher	1	1	1	1	4
Returnee	0	0	4	1	5
Entrepreneur from other indust	0	8	0	1	9
Former executive of SOE	0	3	2	1	6
Other	0	1	0	1	2
Don't know	0	0	0	1	1
All	1	13	7	6	27
Missing	11				

Most of the firms import foreign technology. Transfer of foreign technology is considered as an efficient way to improve the reputation of the firm. Foreign invested firms enjoy more consumer confidence. However, foreign firms are not transferring their most important technologies. According to one opinion the same technology is sometimes imported by several firms who keep the information secret from their local competitors.¹

3. Collaboration and partnering

The response rate on all questions regarding collaboration, partnering and contractual arrangements with other organizations was low.¹ Only one in four enterprises indicated that they had bio-technology related collaboration or cooperative arrangement with other firms or organizations, half of them with a university or hospital. About one in five firms indicated that they were executing R&D for a foreign partner.

4. Patenting

Patenting is one of the measurable outcomes of R&D, especially important for pharmaceutical and biopharmaceutical products and processes. Like other provinces, Guangdong has introduced a program of subsidies rewarding patenting. Seventy percent of firms applied for a patent in China and there were 98 patents pending. Two thirds of enterprises were granted patents from SIPO, the Chinese patent office. The number of patents ranged from 1 to 30, with the median of 2.5 patents per enterprise.

Patenting abroad is still rare. Only three firms patented in the US and obtained 12 US patents, another 11 patents were still pending there. Three firms (two of those that patented in the US) were also granted 13 patents by the EPO, and six were still pending. Two thirds of enterprises have trademarks and about one hundred TMs are related to BT.

5. Financing

Forty percent of surveyed firms attempted to raise capital for BT, mostly for R&D. Eighty percent of demands for financing were successful and the applicants obtained the funds mostly from different level of government. About 60% of firms received government support, mostly in the form of tax credits. Thus financing does not seem to be an insurmountable problem.

6. Foreign trade

Only ten enterprises exported, mostly to Europe (7) and the US (5). More than half of surveyed enterprises imported, mostly intermediate products and raw materials from the US, Europe and Japan. Only about ten percent of imports were products for re-sale.

7. Plans, Strategies and Challenges

Improving and accelerating R&D, developing innovative initiatives and the team spirit of their employees as well as collaboration with partners and universities rank high in the list of strategic knowledge priorities. Obtaining certifications and regulatory approvals for introduction of new products on the domestic and foreign markets and improvement of the public awareness of the firm and its products as means to going global were also mentioned by many firms. Several firms are preparing to enter on the stock market.

The often mentioned difficulties and challenges to further development point to slow, costly and unpredictable regulatory process that takes on average 10 months. Frequent changes in the medical system, reluctant acceptance of new local products by the medical profession, difficulties to hire and retain skilled personnel as well as competition

from big national and foreign pharmaceutical enterprises and the need for financial and professional support for production and marketing were also mentioned.



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