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Indicator-Based Reporting on the Chinese Innovation System 2010

– Life Sciences in China –

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1 Introduction

Life sciences is a term used to define any research that **is concerned with living objects**, either animals or plants. This covers **medicine, biology, biotechnology, genetics, biochemistry, organic chemistry, and others**. There is no strict and clear-cut definition of the term “life sciences”, which is broadly used in this report to also cover medical equipment and instruments as well as pharmaceuticals. As this report is about China and Chinese activities in the life science sector, it is a prerequisite to also focus on TCM (Traditional Chinese Medicine). TCM is to be analyzed in this report only from its technological perspective, although we are aware that TCM involves more than just the herbs, agents, etc.

This report aims to describe the Chinese scientific and technological activities and their international competitiveness in the life sciences sector using quantitative indicators. In consequence, this study only focuses on quantifiable activities and outputs.

2 R&D programs and policies

The role of the life sciences in national policies is a first indication of their standing in the sciences and in the economy in general. As a starting point, policies and programs related to TCM, life sciences, and public health are briefly considered in this section.

The three-year **budget of the Chinese government in public health and medicine from 2009 to 2011 is 850 billion RMB**.[1] In addition, the Ministry of Health of China will receive $5.88 million from the World Health Organization (WHO) in 2010-2011 to support 73 public health programs in more than 20 provinces in mainland China. The key fields in which programs can be funded include public health emergencies, epidemics, food safety, and chronic disease prevention and control, women and children's welfare, medical infrastructure in rural areas, and the development of Chinese Traditional Medicine.[2]

Biotechnology has been identified as one of the frontier technologies in the National Medium- and Long-term Science and Technology Development Plan (2006-2010). Frontier technologies are considered to represent a nation's comprehensive high-tech innovation capability. **Five subfields** – target identification technology, plant-animal species and drug molecular design technology, gene manipulation and protein

1 http://www.gov.cn/jrzg/2009-04/06/content_1278711.htm. Retrieved on March 8 2010.

2 http://www.moh.gov.cn/publicfiles/business/htmlfiles/mohgjhzs/s3578/201003/46177.htm. Retrieved on March 8 2010.

engineering technology, stem-cell based human tissue engineering technology, and new generation of industrial biotechnology – are specifically prioritized.

In the Eleventh National Five-Year Plan (2006-2010), around 30 national S&T centers and laboratories with advanced equipment were to be built in the life sciences and other key fields (IT, aerospace, marine sciences, nanotechnology, and new materials). Additionally, 12 national key S&T infrastructure programs include labs and equipment for protein research and agricultural safety research. Moreover, with respect to technological innovation, important new drugs, epidemic protection and control, as well as modern TCM have been emphasized.[3]

The executive meeting of the State Council recently passed the **implementation plan of the "Major New Medicine Creation"** science and technology program, which is part of the National Twelfth Five-Year Plan, and the call for project applications was announced through three government websites – the Ministry of Health (www.moh.gov.cn), the Ministry of Science and Technology (www.most.gov.cn), and the China National Center for Biotechnology Development (www.cncbd.org.cn). The framework of the program is similar to that in the previous Five-Year Plan, and supports projects in the following five areas: (1) R&D on innovative medicine; (2) Technological upgrade of medicine in major categories; (3) Technology platform building for innovative medicines R&D; (4) Incubation foundation building for enterprises' innovative medicine; and (5) Research on key technologies for new medicines R&D. The financial support ranges from 3 to 25 million RMB for each project, with a goal of (1) promoting indigenous innovation of medicines with minimal side-effects which meet international standards and large market demands, and (2) building technology platforms for facilitating standard development, safety evaluation, R&D, and commercialization.[4].

3 Indicators

3.1 Research and Development (R&D) Expenditure

The expenditure on research and development (R&D) is the basis and foundation of any success in high-tech markets. The expenditures – effectively this means the remunerations of the researchers – are an indication of the amount of R&D activities, which

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3 http://www.gov.cn/ztzl/kjfzgh/content_883887.htm. Retrieved on March 12, 2010.

4 http://www.moh.gov.cn/publicfiles/business/htmlfiles/mohkjjys/s3578/201005/47320.htm. Retrieved on May 26, 2010.

represent the structured and goal-oriented quest for new technologies and new research findings. So R&D expenditure is an input to the innovation process and thereby reflects the activity level or the relevance of certain scientific or technological areas. For these reasons it is important to have information about the level of R&D expenditures and where they are spent.

Table 1: Gross domestic expenditure (in million US$) on R&D by sector of performance and field of science in China, 1998-2007

	1998	2000	2002	2004	2007
Total	55112	89567	128760	196633	371024
Natural sciences and engineering	54154	86564	125199	191898	363378
Natural Sciences	3019	7893			
Engineering	46763	72321			
Medical Sciences	1364	3635			
Agricultural Sciences	3008	2773			
Social sciences and humanities	958	522	1764	2765	5072
Not elsewhere classified (fields of science)		2481	1797	1970	2575
As a percentage of the total					
Natural sciences and engineering	98.3%	96.6%	97.2%	97.6%	97.9%
Natural Sciences	5.5%	8.8%			
Engineering	84.9%	80.7%			
Medical Sciences	2.5%	4.1%			
Agricultural Sciences	5.5%	3.1%			
Social sciences and humanities	1.7%	0.6%	1.4%	1.4%	1.4%
Not elsewhere classified (fields of science)		2.8%	1.4%	1.0%	0.7%

Source: OECD - Main Science and Technology Indicators; Fraunhofer ISI calculations.

China's **expenditure on R&D has increased considerably** over the last decade. The absolute amount in the year 2007 is more than five times the expenditure of 1998 (Table 1). Most of this is dedicated to natural sciences and engineering, which account for 97-98% of total spending. **More than 80% of the expenditure targeted engineering activities** and about another **9% (in 2000) was dedicated to the natural sciences**. Medical sciences account for less than 5%, but increased considerably between 1998 and 2000. In 2007, almost 62% of the business expenditures on S&T activities by large and medium-sized enterprises targeted electronic and communication equipment (Table 2). Another 10% were spent on computer and office equipment R&D and almost 12% on aviation. **Companies spent 13.2% (more than 11.7 billion Yuan)**

on medical and pharmaceutical products research and another 6.1% on medical treatment instruments and meters. It is remarkable that about 32% of the expenditure of large and medium-sized companies on modernizing technical equipment was spent on medical and pharmaceutical products as well as medical treatment instruments and meters. This reflects, on the one hand, the necessity to invest in the laboratories and research institutions. On the other hand, this also reflects the demand – or at least the intention – to rejuvenate the input into the R&D system and the goal of becoming competitive on an international level.

Table 2: Inputs of large- and medium-sized enterprises in science and technology activities in high-tech sectors (2007)

Industry	R&D Personnel	FTE* R&D Personnel	FTE* Scientists and Engineers	Expenditure on S&T activities (10 000 CNY)	R&D expenditure	Expenditure for new products	Investment in (10 000 CNY)
Total	478284	248228	213822	8868253	5453244	6520284	2109878
Medical and pharmaceutical industry	73408	30778	25377	1169417	658836	739435	473091
Chemical medicine	45227	19302	15558	726795	418799	470476	315245
Traditional Chinese Medicine (TCM)	18005	7420	6519	273222	156873	176588	112305
Biological & biochemical products manufacturing	5427	2769	2294	93701	55225	51628	15756
Medical equip. and instr. manufacturing	39822	18148	15330	544915	305093	400493	204991
Medical equipment and instruments	6637	3468	2935	105818	73163	87086	41668
Other equipment and instruments	33185	14680	12395	439097	231930	313408	163323

Note: * FTE = Full time equivalents; S&T means Science and Technology, which is a broader term than R&D as it covers additional expenditures.

Source: China Statistical Yearbook (2008); Fraunhofer ISI calculations.

Table 3 shows the distribution of NSFC-funded **life sciences and TCM** projects in the period 2001 to 2008. As can be seen, the number of projects has a more or less constant share slightly above **1/3 in the portfolio of the National Science Foundation of China**. Less than 3% of all NSFC projects concern Traditional Chinese Medicine. The rate of acceptance of TCM projects is also quite constant. One project out of 7 or 8 applications is finally funded by the NSFC.

Table 3: The distribution of NSFC-funded life science and TCM projects**, 2001-2008

	Life sciences**	TCM	Total NSFC	LS/Total	TCM/Total
2001	1,667	107	4,931	33.8%	2.2%
2002	2,406	203	6,676	36.0%	3.0%
2003	2,619	177	7,097	36.9%	2.5%
2004	3,314	252	8,619	38.4%	2.9%
2005	3,539	251	9,831	36.0%	2.6%
2006	4,107	297	11,246	36.5%	2.6%
2007	4,944	384	14,169	34.9%	2.7%
2008	5,889	431	16,414	35.9%	2.6%

Source: Deng, Xu (2009); Fraunhofer ISI calculations.

Note: *NSFC-funded projects are classified into general, key, and major projects **Life sciences include many sub-fields: microbiology, botany, ecology, forestry, biophysics, biochemistry, molecular biology, immunology, neurology, cognitive psychology, physiology, integrated biology, genetics, bioinformatics, cytobiology, biology of reproduction and evolution, food science, agriculture and agronomy, horticulture, plant protection and nutrition zoology, zootechnics, veterinary medicine, and fishery science.

Table 4: Applied and accepted NSFC projects in the field of TCM, 2001-2008

	Applied amount (million RMB)	Accepted amount (million RMB)	Rate of acceptation (projects)
2001	169.5	19.0	12.8%
2002	220.3	26.0	14.0%
2003	243.1	30.9	16.0%
2004	12,233.5	44.4	15.7%
2005	9,589.9	57.6	12.6%
2006	721.8	71.3	12.2%
2007	2,243.5	58.8	11.4%
2008	4,426.2	76.6	13.3%

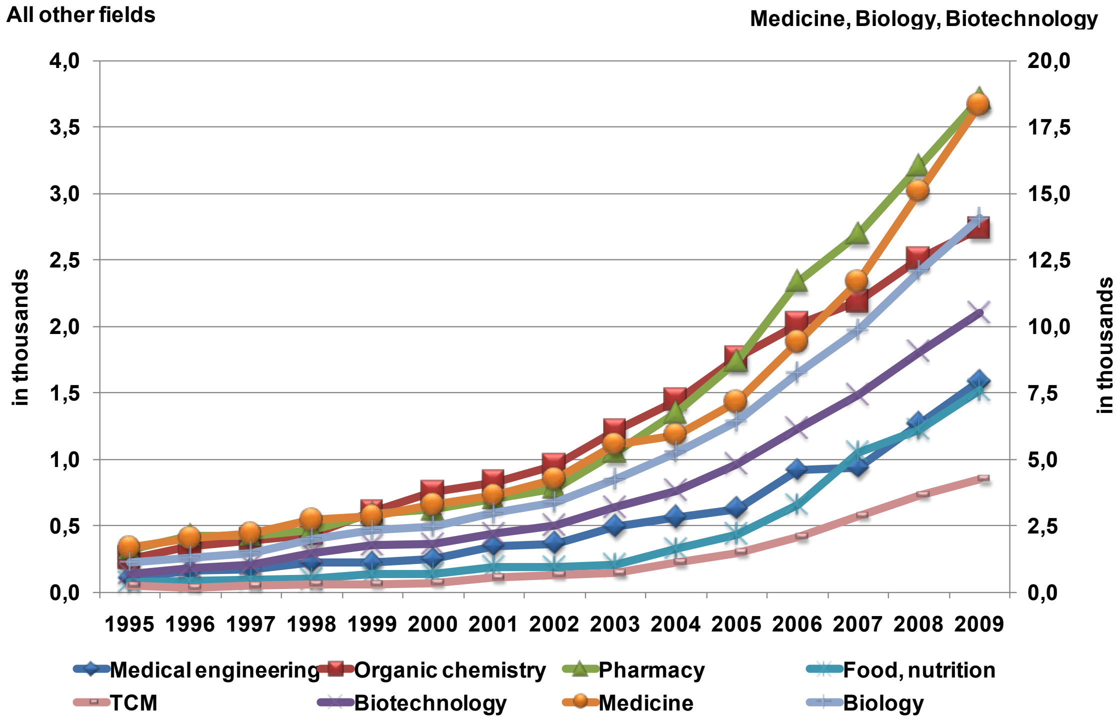
Source: Deng, Xu (2009); Fraunhofer ISI calculations.

3.2 Publications

The research output of Chinese authors in terms of scientific publications has undergone and is still undergoing enormous growth rates. The numbers of SCI-publications quadrupled in the period between 2001 and 2009. **Life science publications grew above the Chinese average in the last decade.** Figure 1 depicts the absolute numbers of scientific papers covered by the Science Citation Index. The largest fields are –

similar to the profile in other countries – medicine, biology and biotechnology, whereas Traditional Chinese Medicine, food and nutrition, or medical engineering are rather small fields in terms of scientific publications. Organic chemistry is the slowest growing area among the fields analyzed. _Here, the numbers "only" tripled between 2002 and 2009.

Figure 1: Absolute number of Chinese SCI publications in life science subfields, 1995-2009



Source: STN – SCISEARCH; Fraunhofer ISI calculations.

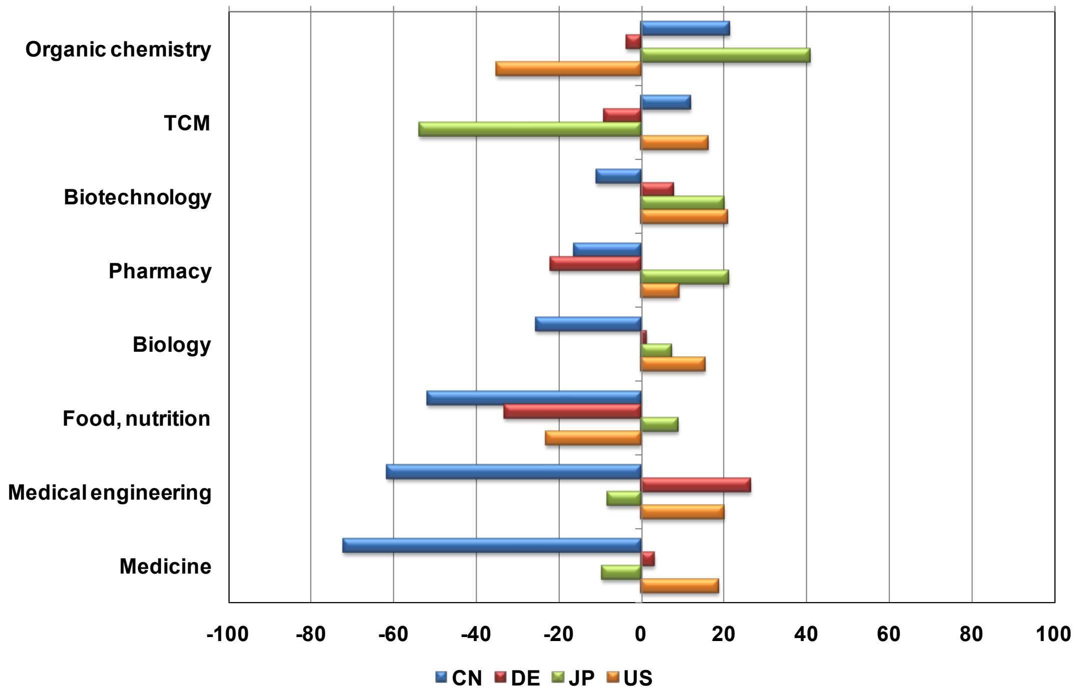
The fastest growing fields were food and nutrition as well as Traditional Chinese Medicine. However, China overall reaches a level of 11.3% of worldwide publications in 2009, and **only organic chemistry (13.9%) and TCM (12.7%) have higher than average shares**. It is interesting to note that the **share of Chinese authors is lowest in medicine (4.9%)** and also rather low in medical engineering and food and nutrition. In consequence, the specialization profile – this indicator benchmarks the national activities against the world-wide profile – of SCI publications in the life sciences does not reveal many comparative advantages. Only organic chemistry and TCM are higher than the world-wide average. **In terms of international relevant research output, Chinese strengths do not include medicine, medical engineering, food and nutrition.** This research profile is in almost complete contradiction to the profiles of the industrialized countries of Germany, Japan, and the USA. The poor performance of China in the area of medicine, combined with the fact that this field is the largest one considered here, is one of the most striking findings of this analysis. If the international alignment – this is an index of internationalization – is used, this finding becomes even more prominent. All the life science fields have negative values. This means that Chinese authors are not very well represented in internationally prominent journals. Concerning scientific regard – this is a relative citation rate that can be seen as an **indication of quality** – the overall Chinese performance is now slightly above the world average, but in life sciences **only organic chemistry manages a positive value**. Medical engineering, pharmacy, and biotechnology are close to the average and the large fields of medicine, biology, as well as food and nutrition are below the world-wide average. **This means that the relatively lower number of Chinese scientific publications in medicine or biology is not really targeting an international audience, and at the same time, is of rather low quality.** In sum, China does not feature among the best performers in life sciences research. Although positive trends are also visible in these areas, the life sciences in general are not fields, in which Chinese authors show the most outstanding achievements.

Table 5: Share of Chinese SCI publications in life science subfields in world-wide publications, 1995-2009

	1995	2000	2005	2009
Medical engineering	0.7%	1.3%	2.9%	6.0%
Organic chemistry	1.8%	4.6%	9.4%	13.9%
Pharmacy	1.3%	2.4%	5.6%	9.8%
Biotechnology	1.0%	2.2%	5.4%	10.7%
Food, nutrition	0.7%	1.0%	2.7%	6.7%
Medicine	0.7%	1.2%	2.3%	4.9%
Biology	1.0%	2.0%	4.9%	9.1%
TCM	2.3%	2.3%	6.8%	12.7%
Total	2.1%	3.9%	7.7%	11.3%

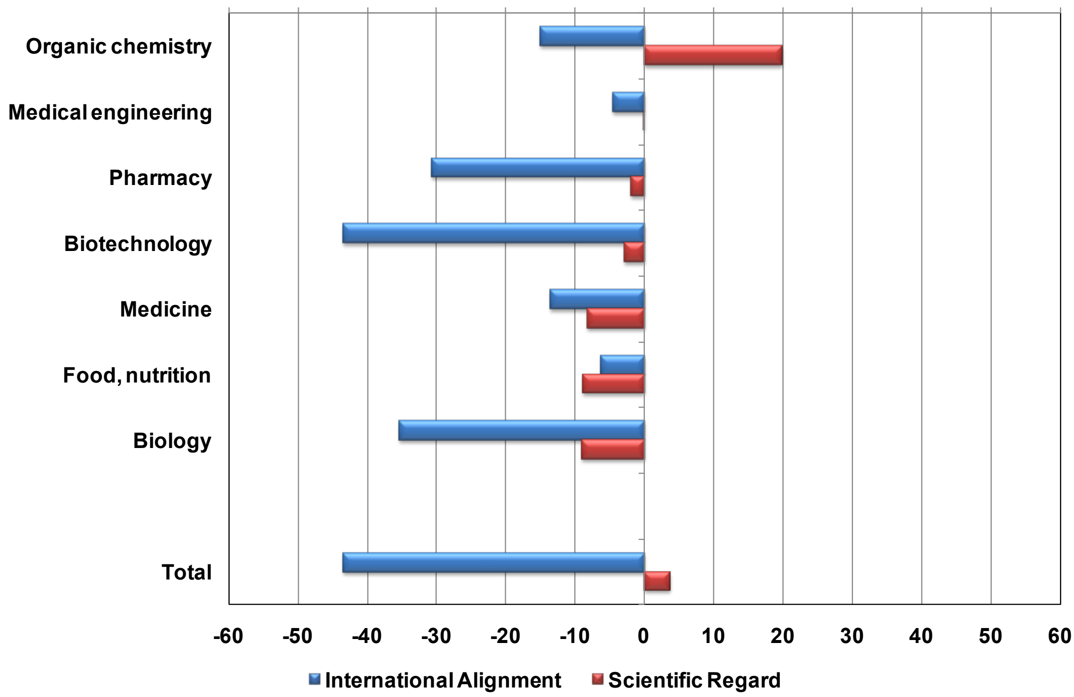
Source: STN – SCISEARCH; Fraunhofer ISI calculations.

Figure 2: Specialization profile of SCI publications in life science subfields of four selected countries, 2007-2009



Source: STN – SCISEARCH; Fraunhofer ISI calculations.

Figure 3: International alignment and scientific regard of Chinese SCI publications in life science subfields, 2006*



* Note: A 3-years citation window is applied. The latest available publication year is therefore 2006.
Source: Schmoch, Schulze (2010); Fraunhofer ISI calculations.

To assess not only the quantity but also the quality of Chinese publications in the life sciences, the impact factor of the SCI was used to analyze the number of publications in the top 20 scientific journals. As can be seen in Table 6, the share of Chinese articles in the top journals is quite low. Except for organic chemistry and food and nutrition, Chinese authors are hardly able to get published in the best journals in the seven subfields of the life sciences analyzed here. The top ten publishing institutions are listed in more detail in Tables 7a-7g.

Table 6: Number and share of Chinese articles in the top 20 journals in the life sciences

	Articles with Chinese author(s)	Total N of articles	% of Chinese articles
Medical engineering	616	17206	3.6%
Organic Chemistry	3542	29929	11.8%
Pharmacy	340	9277	3.7%
Biotechnology	210	12213	1.7%
Food and Nutrition	1322	18711	7.1%
Medicine	314	21280	1.5%
Biology	145	5307	2.7%

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

Table 7a: Top institutions publishing in the top 20 journals: medical engineering

The University of Hong Kong	**36**
Peking University	36
Fudan University	32
Ministry of Education China	28
Sun Yat-Sen University	27
Chinese Academy of Sciences	26
Beijing Normal University	26
Prince of Wales Hospital Hong Kong	26
Zhejiang University	24

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

Table 7b: Top institutions publishing in the top 20 journals: organic chemistry

Shanghai Institute of Organic Chemistry Chinese Academy of Sciences	**547**
Zhejiang University	226
State Key Laboratory of Applied Organic Chemistry	156
Nankai University	152
Beijing National Laboratory for Molecular Sciences	147
Peking University	141
Fudan University	140
Chinese Academy of Sciences	133
Graduate University of Chinese Academy of Sciences	101
Wuhan University	95

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

Table 7c: Top institutions publishing in the top 20 journals: pharmacy

Shanghai Jiaotong University	**26**
Peking University	**21**
Shanghai Institute for Biological Sciences Chinese Academy of Sciences	20
Fudan University	19
Shandong University	18
The University of Hong Kong	17
Shanghai Institute of Materia Medica, Chinese Academy of Sciences	15
China Pharmaceutical University	13
Chinese Academy of Medical Sciences	13
Shenyang Pharmaceutical University	12

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

Table 7d: Top institutions publishing in the top 20 journals: biotechnology

The University of Hong Kong	**18**
Peking University	16
National Institute of Biological Sciences, Beijing	11
Shanghai Institute for Biological Sciences Chinese Academy of Sciences	9
Ministry of Education China	8
Chinese University of Hong Kong	8
Chinese Academy of Sciences	8
Shanghai Jiaotong University	8
Tsinghua University	8

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

Table 7e: Top institutions publishing in the top 20 journals: food and nutrition

China Agricultural University	**120**
Zhejiang University	115
Chinese Academy of Sciences	76
Jiangnan University	74
Nanjing Agricultural University	60
The University of Hong Kong	58
Chinese Academy of Agricultural Sciences	51
South China University of Technology	45
Chinese University of Hong Kong	44
Southern Yangtze University	42

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

Table 7f: Top institutions publishing in the top 20 journals: medicine

Chinese University of Hong Kong	**30**
The University of Hong Kong	28
Peking University	20
Prince of Wales Hospital Hong Kong	15
The Fourth Military Medical University	15
Chinese Center for Disease Control and Prevention	14
Xijing Hospital	11
Shanghai Jiaotong University	9
Fuwai Hospital	9
Ministry of Health of People's Republic of China	9

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

Table 7g: Top institutions publishing in the top 20 journals: biology

National Institute of Biological Sciences, Beijing	**20**
Institute of Genetics and Developmental Biology Chinese Academy of Sciences	19
Peking University	16
China Agricultural University	12
Yale University	9
Institute of Botany Chinese Academy of Sciences	9
Chinese Academy of Agricultural Sciences	9
The University of Hong Kong	8
Institute of Plant Physiology and Ecology, Shanghai Institute for Biological Sciences CAS	8
Tsinghua University	7

Source: Elsevier – Scopus; Fraunhofer ISI calculations.

3.3 Patents

Patent applications are one output measure of R&D activities, especially of companies. On the one hand, these are a good and reliable indicator due to their procedural requirements. On the other hand, patents are much more application-oriented than for example scientific publications, as they provide information about technical solutions for very specific problems. The life sciences patents have been discussed for a long time and recently especially gene patents as well as patent protection for certain pharmaceuticals (e.g. AIDS treatment medicine) have been challenged by the public. Life sciences are the only area in which the system of patent protection is being contested in this way.

Table 6 shows the absolute number of Chinese patent applications to the State Intellectual Property Office (SIPO) of China between 1996 and 2007, which is currently the most recent year available for patent analyses.[5] Again, the **absolute numbers of Chinese patent applications have grown very rapidly** and this growth has even accelerated recently. In parallel to the overall growth at the SIPO, the shares of Chinese inventors in relation to the total applications to the office (including also foreigners' filings in China) have also grown. In other words, **Chinese inventors were mainly responsible for the overall growth in patent applications at the SIPO**. In 2007 63.5% of patents filed in China had Chinese inventors (and in consequence 36.5% were foreigners). It is interesting to note that, **in genetics, in TCM, as well as in biotechnology and pharmaceuticals, the shares of Chinese inventors in China are far above this average**. Medical instruments as well as organic basic materials do not show above-average activities by Chinese inventors. The share of electronic medical instruments is extremely low (42.5%) and the absolute number of 767 filings in relation to the total of almost 116.000 is also low.

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5 As patents are used here as an output of R&D processes, the date of world-wide first patent filing – the so called priority date, which is the earliest recorded date in the patent system – is the most appropriate as this comes closest to the date of invention. Patents are published with a delay of 18 months after application, so 2007 is the latest completely available priority year in 2010. The 2007 priority filings were published in the years 2008 and 2009 (18 month delay). Only the respective patent office – in this case SIPO – is able to publish statistics on the more recent priority years without the 18 months delay. However, they only publish rather general statistics so that analytical depth is not possible, e.g. in the subfields of the life sciences.

Table 8: SIPO (invention patents) and transnational* patent applications of Chinese inventors in the field of life sciences, 1996-2007

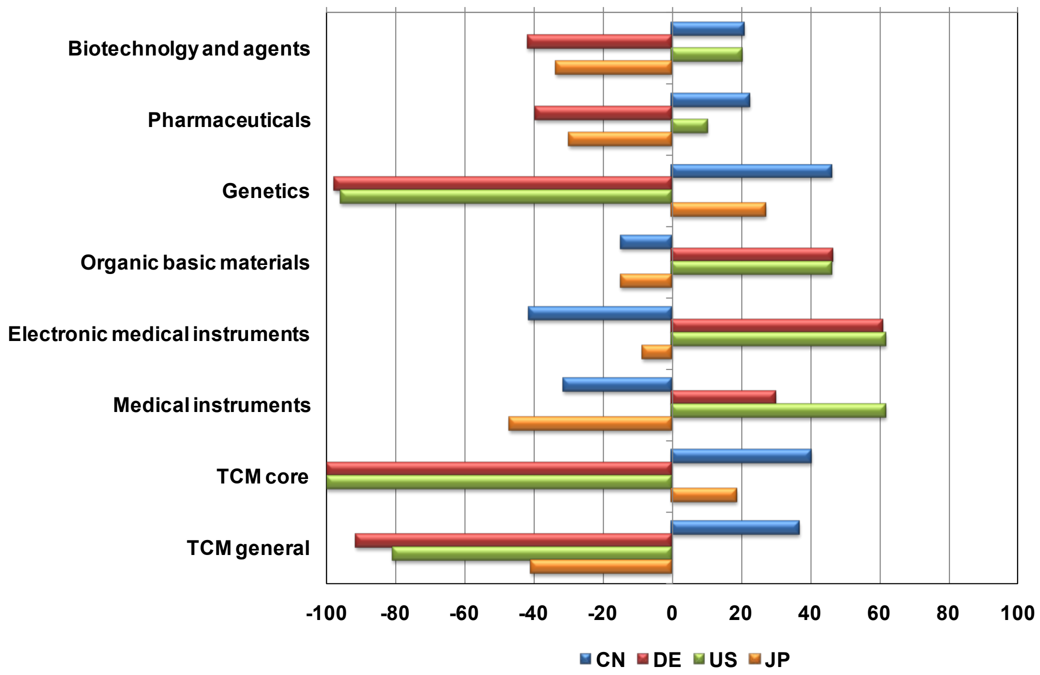
	1996	2000	2004	2007	% of total in 2007
	SIPO applications				
Biotechnology and agents	748	4,862	5,889	9,918	78.5%
Pharmaceuticals	1,034	4,950	6,891	10,211	77.8%
Genetics	156	1,159	1,574	1,571	95.9%
Organic basic materials	177	1,993	1,277	2,195	62.2%
Electronic medical instruments	72	148	426	767	42.5%
Medical instruments	212	356	803	1,485	51.4%
TCM core	502	889	7,160	7,157	71.7%
TCM general	240	971	3,763	3,742	95.2%
Total	10,135	22,897	63,775	115,882	63.5%
	Transnational applications				
	1996	**2000**	**2004**	**2007**	**% of total in 2007**
Biotechnology and agents	27	1,006	262	507	2.7%
Pharmaceuticals	26	1,005	256	492	2.9%
Genetics	11	699	59	93	3.1%
Organic basic materials	7	38	76	224	3.6%
Electronic medical instruments	1	7	20	94	2.3%
Medical instruments	4	28	71	125	1.5%
TCM core	12	33	40	85	5.5%
TCM general	18	602	146	313	3.3%
Total	229	1,821	3,037	7,619	3.6%

Note: TCM core covers medicinal preparations and selected foodstuffs with ingredients from animals or plants. TCM general covers medicinal preparations with organic ingredients in general. * Transnational patents are families with at least a PCT and an EPO application (see (Frietsch, Schmoch 2010).

Source: EPA – PATSTAT; Fraunhofer ISI calculations.

What has been said so far only holds for the SIPO, which of course only covers the Chinese market for technologies. To assess the international competitiveness of life science technologies made in China, an international market perspective is necessary. This is taken by examining the transnational patent applications (Frietsch, Schmoch 2010), which are patent families that have at least one member filed at the European Patent Office or via the Patent Cooperation Treaty administered by WIPO (World Intellectual Property Office). Whereas the absolute numbers here grew very quickly, **the performance of Chinese life sciences is still rather restricted on an international level**. While Chinese inventors hold a share of 3.6% in total transnational applications, the Chinese shares are below this level in all the life sciences fields, except for Traditional Chinese Medicine and organic basic materials. It is worth mentioning that the numbers for the year 2000 are biased due to a single company called BioWindow, which filed more than 1000 patents in the years 1999 and 2000 on an international level, none of which, however, passed the early examination phase. This company's applications were mainly in the areas of biotechnology, pharmaceuticals, and genetics.[6] BioWindow filed patents that were very similar to other applications and to other companies' findings so that prior art existed and the novelty[7] criteria, which any patent has to fulfill on the international level, was violated. This company was "inspired" by the human genome project (Frietsch, Wang 2007).

Figure 4: Specialization profile of SIPO patent applications, 2005-2007



Note: TCM core covers medicinal preparations and selected foodstuffs with ingredients from animals or plants. TCM general covers medicinal preparations with organic ingredients in general.
Source: EPA – PATSTAT; Fraunhofer ISI calculations.

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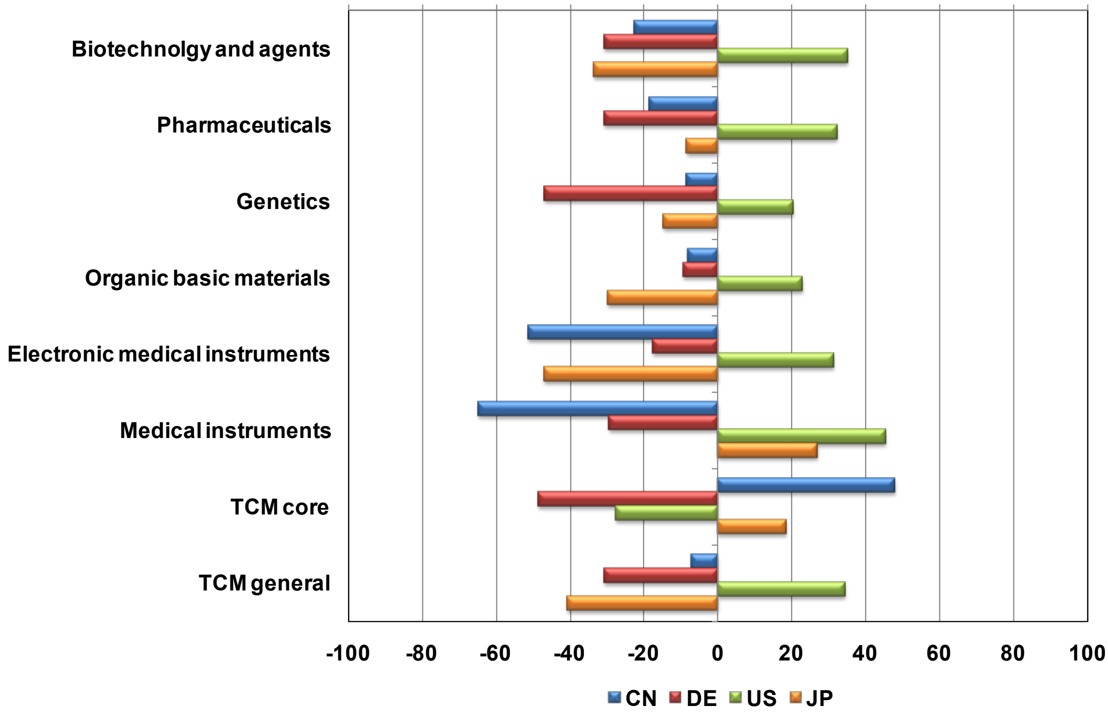
6 These fields are not completely distinct in terms of the underlying patent classification so that some double counting has to be accepted

7 On an international level the novelty criteria means world-wide novelty. Until the recent reform of the Chinese patent law, the novelty criteria at SIPO effectively only covered applications filed in China, so only Chinese prior art was taken into account. Furthermore, public use and public knowledge of certain technologies in China and not world-wide were taken as prior art. In 2009 the world-wide standard of examination of prior art was also introduced in China, but it remains to be seen whether it will be effectively applied in the same way.

The patent applications filed at SIPO are depicted in Figure 4. **Chinese inventors are relatively strong in biotechnology, pharmaceuticals, genetics, and TCM , while they are comparatively weak on a national level in organic basic materials and especially medical instruments.** Again, as was the case with scientific publications, this profile is very different to what the three large industrialized countries Germany, the USA, and Japan are doing in China. Germany and the USA are especially active in medical instruments and organic basic materials, while Japanese inventors do not engage in the life sciences in China, apart from some activities in genetics and Traditional Chinese Medicine (or its Japanese equivalent).

The technological competitiveness on a transnational level is shown in Figure 5, which clearly shows that the United States is the dominating country in the life sciences on a world-wide scale. At the same time, it also becomes evident that **China is not able to prove any comparative advantage in the life sciences on a transnational level**. Only Traditional Chinese Medicine (or its equivalent like homeopathic or alternative medicine) stands out on the plus side for China. The biggest deficiencies are visible once again in the area of medical instruments.

Figure 5: Specialization profile of transnational* patent applications of selected countries, 2005-2007



Note: TCM core covers medicinal preparations and selected foodstuffs with ingredients from animals or plants. TCM general covers medicinal preparations with organic ingredients in general. * Transnational patents are families with at least a PCT and an EPO application (see (Frietsch, Schmoch 2010).
Source: EPA – PATSTAT; Fraunhofer ISI calculations.

3.4 Foreign Trade

At the end of the day, the markets for goods and commodities are where all the research and development as well as patenting activities have to take effect, in one way or the other. As the largest exporting country in the world, China has to transfer investments in science and technology to international markets for high-tech goods. It is these international markets, where the Chinese have to prove their abilities and capabilities on a competitive basis. Based on this, strengths and weaknesses in science and technology applications can be assessed in a comparative way.

Table 9: China's shares of world trade and export-import balance in life sciences, 1995-2008

	1995	2000	2005	2008
	High-tech			
Biotechnology and agents	6.3%	1.7%	1.0%	0.8%
Pharmaceuticals	0.3%	-0.9%	-0.6%	-0.5%
Organic basic materials	-14.4%	-11.6%	-9.1%	-3.0%
Electronic medical instruments	-2.8%	-1.3%	-0.5%	-0.1%
Medical instruments	0.0%	0.3%	0.3%	0.4%
	All life sciences			
Sap, pectin, mucilage, algae, herbal substances	1.0%	0.2%	0.1%	0.1%
Organic chemical products	-12.7%	-11.4%	-8.8%	-2.6%
Medicine and pharmaceuticals	8.8%	1.3%	0.6%	0.4%
Essential oil, scents, polish, soaps	-2.9%	-0.9%	-0.2%	-0.1%
Medical instruments	0.1%	0.3%	0.3%	0.3%

Source: UN – COMTRADE; Fraunhofer ISI calculations.

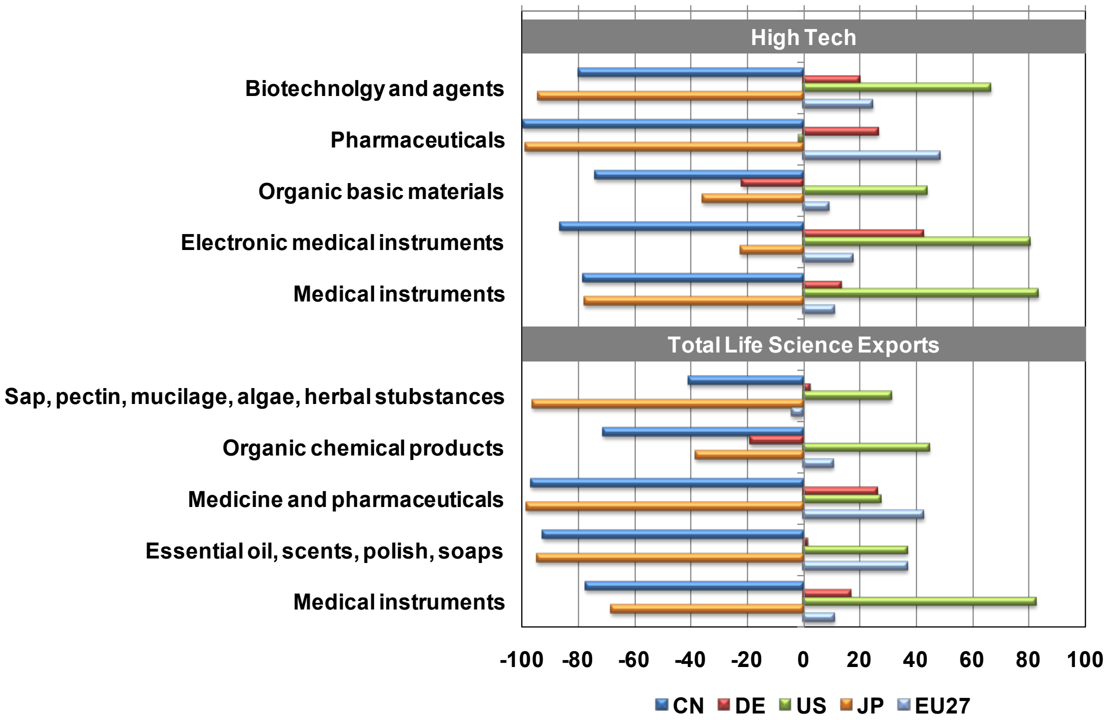
China's export profile is characterized by enormous differences ranging between leading-edge technologies, which require high investment in R&D, and low-tech areas, where price competition is more relevant than technology or quality competition. At present, **China is solely responsible for more than 16% of the world-wide exports of processed goods**. However, the finding from the analysis of scientific publications as well as patents, namely that the **life sciences are not a Chinese strength, also holds for international trade**. If all the life sciences-related goods are taken into account, China has the largest shares in sap, pectine, algae and the likebut only accounts for 2.3% of the global trade in medicine and pharmaceuticals, a figure which is even decreasing over time. When looking at the high-tech areas only, the situation is even clearer: **the world-wide production of pharmaceuticals does not take place in China and the Chinese world market shares have actually fallen since the mid**

1990s. Even if it is taken into account that the Chinese exports are dominated by ICT-related goods and that these technologies are responsible for the overall huge share of China in world-wide trade, the market shares of 5.5% in biotechnology, 7.6% in organic basic materials and 5-6% in medical instruments are still far below what would be expected from a technology-oriented country of the size of China.

The export-import-balance provides indications for the Chinese supply and demand of life sciences goods on world markets. The lower panel of Figure 7 illustrates data in relation to the overall Chinese trade surplus of processed goods. In 2008 an almost balanced pattern results, while until recently especially organic basic materials but also medical instruments had a trade deficit. Biotechnology and agents as well as medicine and pharmaceuticals were exported more than imported between the mid 1990s and the mid 2000s, but their contribution to the trade surplus has diminished over time. This, however, is a direct effect of the **increasing Chinese demand for biotechnology and pharmaceuticals that has not been accompanied by a similar increase of the Chinese supply in international markets**.

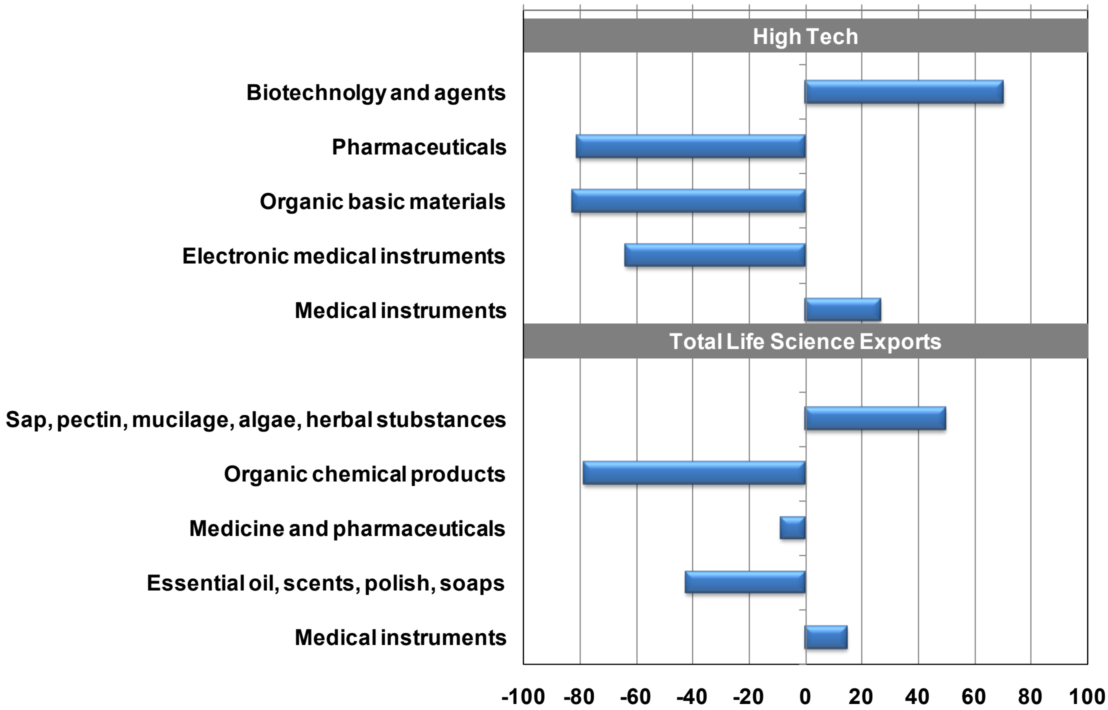
In consequence, the export specialization profile of China does not show any positive values in the life sciences, either in high-tech or in total life sciences exports. Figure 6 again provides evidence for the strong position of the US in the life sciences and also for some comparative advantages for Germany in these fields.

Figure 6: Export specialization profile of selected countries, 2006-2008



Source: UN – COMTRADE; Fraunhofer ISI calculations.

Figure 7: China's export-import specialization profile (revealed comparative advantage (RCA)), 2006-2008



Source: UN – COMTRADE; Fraunhofer ISI calculations.

4 Summarizing conclusions

The life sciences – that is medicine, biology, biochemistry, biotechnology and several other adjacent areas like medical instruments or food and foodstuffs – do not currently feature among China's strengths. Considerable comparative advantages for China can neither be detected concerning scientific publications nor in terms of patents. While organic chemistry and Traditional Chinese Medicine have an activity level above the world-wide average if scientific publications are taken into account, areas like biotechnology and pharmaceuticals are slightly below, while medical equipment and especially medicine are far below the world average. Increases in the relative position can be detected in almost all areas, but the largest field of medicine shows a rather smooth change. This finding is also supported by a recent study on China's scientific output (Adams et al. 2009). Biology is among the fastest growing areas, but the shares in worldwide publications in all life science fields still remain far below the Chinese average.

Genetics and Traditional Chinese Medicine feature prominently in the patent applications of Chinese inventors to the State Intellectual Property Office (SIPO) of China, while medical equipment and organic chemistry are not among their strengths. The Chinese profile is completely different on the international technology markets. Although some strengths in genetics and in Traditional Chinese Medicine are still visible, it becomes even more evident that no comparative advantages exist in medical equipment, even though this area has been among the most dynamic ones in recent years. The patent activities in biotechnology and pharmaceuticals are not able to meet international expectations, but those in organic chemistry almost reach the international average unlike the national context. These findings suggest two effects: On the one hand, it seems that foreign activities in China are focused on certain areas (medical instruments and chemistry). This is why it is much harder for Chinese inventors to reach a relatively good position in the Chinese technology market. On the other hand, these results corroborate once again that the national activities are not yet internationally competitive in all areas and that, so far, there are no comparative advantages compared to the established industrialized and innovation-oriented countries.

Trade deficits exist in organic basic materials, in pharmaceuticals and in parts of medical equipment, which means that China imports more of these goods than it exports. If biotechnology products are considered, the picture changes and China achieves a trade surplus, albeit with a decreasing trend, as the national demand is growing even faster than the supply to international markets. Furthermore, China does not occupy an above-average position in the world markets in any of the life sciences or adjacent areas. China's share in world-wide exports of processed goods was 15.7% in the period 2006 to 2008. This share is dominated by information and communication technologies. Its share in the world trade of pharmaceuticals was only 0.7% with a decreasing tendency and the other goods like biotechnology, organic chemistry or medical instruments are also clearly below the Chinese average with values between 4 and 6%.

It has to be emphasized that the Chinese government and Chinese companies have been able to greatly increase the expenditures on R&D in recent years, also in the fields of the life sciences. Between 2000 and 2007 total expenditure more than quadrupled which may also correspond to a similar increase in the life sciences. A recent study on the Chinese biotechnology market names China as the fastest growing market in the world and bases this conclusion on a survey of almost 4,500 small and medium-sized companies supposed to have an increasing number of drugs in the preclinical or even clinical phase, with a considerable number even in the pre-registration phase (Raabe, Leewe 2010). However, another recent study (Bührlen, Vollmar 2009) surveying biomedical innovation and clinical research does not list China among the top countries. Although they show the highest growth rate, the number of clinical tests is on the same absolute level as much smaller countries like Denmark, Austria or South Korea.

Despite that fact that our empirical data did not reveal any strong positive trends, it is important to acknowledge the increased efforts on the input side. The National Science Foundation of China (NSFC) has more than tripled its number of life sciences projects and it still spends more than one third of its funding on projects in this area. A small number (about 2-3%) of NSFC projects deals with Traditional Chinese Medicine. This is an area of great hope for China in an international market perspective as well. But these high hopes cannot yet be backed up by empirical data, even though China shows some strengths in terms of publications and patent filings. It has to be stressed that other countries also conduct similar research and have been able to transfer their research into patents and products – although they call this homoeopathic or alternative medicine rather than Traditional Chinese Medicine.

While the Chinese innovation system in general is characterized by enormous growth rates on the input side and some respectable successes on the output side, this is not yet true for the life sciences. The major challenge for China is the transfer of research, development, and patents to industry and markets. In terms of the life sciences, the challenges here are even larger as there is not only an enormous gap to overcome. Because the life sciences are a field in which traditional, industrialized countries are actively engaged, they are continuing to build on their currently very strong relative position, so that closing this gap will be even harder to do.

A.1 Annex: Case Studies of TCM Companies in China

A.1.1 Tong Ren Tang (TRT)

Beijing TRT has a history reaching back over 340 years and is a well-known brand in the traditional Chinese medicine industry.[8] Under the overall framework of the TRT Group, three businesses have been established, namely, modern pharmacy, a retail business, and medical services. The group currently has 2 listed companies (on the Shanghai Stock Exchange and the Hong Kong Stock Exchange GEM), and more than 800 retail stores at home plus 36 joint venture stores in another 15 countries and regions. In addition, some new products have entered a mature market stage.

Beijing TRT Hospital of TCM combines medicine and medical treatment featuring the TRT brand and TRT traditional Chinese culture. The hospital not only provides Chinese traditional medicine (supplemented by western medicine), but has also established a service system including an expert outpatient service, general outpatient service, inspection centre and wards.

Since 2000, TRT has established 13 traditional medicinal plantations according to the Medicinal Collection and Planting Regulations (GCAP) standards (7 of them have passed GCAP certification) involving a total investment of 58 million RMB. TRT has recently been paying more attention to research and innovation. The Beijing TRT Research Institute was established with funding from the TRT Group, the Chinese Academy of Chinese Medical Sciences, and two pharmaceutical companies, and has embarked on research and development in natural medicine, bio-medicine, food and healthcare products, as well as cosmetics.

By the end of 2009, TRT had maintained a 2-digit growth rate in thirteen consecutive years. The sales for 2009 exceeded 10 billion RMB and the profits 0.8 billion RMB, increasing 12% and 16% since 2008, respectively. TRT earned $25.4 million in exports in 2009, an increase of 10.3% since 2008, and is ranked No.1 in the TCM industry in China. At present, TRT holds total assets worth 10.2 billion RMB and has about 14,000 employees.

A.1.2 Tasly

Tasly, founded in 1994, is a younger entrant to the TCM industry. By sticking to the pharmaceutical industry, aiming at a broad healthcare industry, and adopting scientific research and innovation, Tasly has become a hi-tech group whose business encom-

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8 http://www.tongrentang.com/en/abouttrt/profile.php. Retrieved on March 3, 2010.

passes modern TCM, chemical medicine, biological medicine, healthcare products, and functional food.

The main products and markets for Tasly are anti-virus medicine, anti-flu medicine, cardiovascular medicine, cerebrovascular medicine, anti-tumor medicine, immune system medicine, and digestive system medicine.

Tasly has built up three production bases. The first is dedicated to the production of modern TCM and is based in Tianjin. The second is located in Shanghai and focuses on biomedicine production, whereas the production base in Jiangsu targets chemical medicine – traditional Western and Chinese medicine. Finally, a herbal plantation is located in Shanxi. There are 6 regional subsidiaries and 191 local offices in China under the framework of the Group. Moreover, the Tasly Group has set up two systems for the international market, international trade and international direct sales, covering 20 countries and areas from developing to developed countries.

Tasly has continuously invested in and promoted their scientific and innovative activities. It has established a national technology centre for enterprises and a national post-doctoral scientific research institution.

Tasly always emphasizes the protection of intellectual property rights. By the end of 2006, Tasly had applied for 694 intellectual property rights, among which are 599 patents of invention, and 22 international PCT patents. Its major products have been registered in 34 countries and regions. Tasly has ambitious and clear plans for internationalization.

In the period between January and November in 2009, the sales of the Tasly Group reached 6.93 billion RMB and the profits were 0.84 billion RMB, an increase of 16% and 46%, respectively, compared to the same period in 2008. By the end of 2007, the total assets of the Group reached 8.5 billion RMB, and the revenue in sales from the overseas market exceeded $80 billion. Note that its sales in Africa have doubled annually for three consecutive years. Based on its quick growth in the international market, Tasly has set itself a new goal of making 50% the annual growth rate in sales and profits.

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