REVIEW

China and the global stem cell bioeconomy: an emerging political strategy?

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There is a growing consensus, amongst policy analysts and scientists alike, that China is likely to play a key role in the scientific, clinical and commercial development of stem cell research. However, to date, there exist few detailed analyses of China's current investment in the field. After introducing the UK's recent political strategy on stem cell science, this article develops an in-depth discussion of the formal organization of China's research and development in the area, as well as its rapidly evolving commercial, regulatory and ethical environment. From here, we go on to assess the probability of China's emergence as a global player in the increasingly internationalized business of stem cell biomedicine.

In November 2005, the UK's Stem Cell Initiative published its report and recommendations (the Pattison Report), swiftly accepted by the government, setting out a 10-year strategy for the development of stem cell research, therapy and technology. The ambition is 'for the UK to consolidate its current position of strength in stem cell research and mature…into one of the global leaders in stem cell therapy and technology' [1]. In pursuit of this objective, the report employs both a particular understanding of the relationship between stem cell science and the market and a particular view of how the state should contribute to the development of that relationship. Effectively, the report sets out the UK's political strategy on the stem cell bioeconomy.

Although probably the most detailed national statement on this bioeconomy, it is by no means the only interpretation available in the global policy debate on stem cell science. In countries such as France, the state has taken a far less interventionist stance, whereas in others, such as China, Singapore and South Korea, it has made the advance of stem cell science a matter of national importance requiring the investment of considerable public resources. Interpretations of what forms of intervention a government should adopt as part of its political strategy also vary widely. What analysis does it have of the routes for the commercialization of stem cell science and the contributions to be made by the state? In the UK's case, the Pattison Report recommendations are based on a view of:

- The appropriate level of state investment in basic and translational stem cell science and the contribution that may (or may not) be anticipated from private venture capital at particular points in the commercialization process;
- The organization and coordination of the infrastructure of the science through Centers of Excellence, Cell Therapy Production Units and the UK Stem Cell Bank;
- The maintenance of public (and therefore consumer) confidence through the regulation of the basic science, its clinical applications and animal experimentation, coupled with public dialog;
- Support for investor confidence through appropriate legislation on intellectual property rights;
- Engagement with the private sector, notably the pharmaceutical industry, through a public–private consortium focusing on the development of predictive toxicology tools from stem cell lines as an intervening stage in a commercialization strategy.

Precisely what strategy, if any, is adopted depends not only on a government's understanding of the stem cell science–market relationship but also on its response to the local and regional factors that may influence and shape that relationship. These factors include the economic (e.g., the regional structure of financial markets and the venture capital industry [2,101]), the cultural (e.g., the value attached to the embryo in human embryonic stem cell research by different national cultures [3]) and the political (e.g., the role of regional government and international agreements [102]). In assessing whether and how to position themselves in the global tissue economy, governments are obliged to respond to these factors as they formulate their policies on stem cell science and its commercialization.

Keywords: China, globalization, regulation, science policy, stem cells

future medicine

Several countries in East Asia are easily a match for the UK in their ambitions for stem cell science as they plan the way forward for their transitional economies. Despite (or because of) the fallout from the Hwang affair, South Korea remains firmly committed to the aggressive expansion of stem cell research and, in May, announced the allocation of US$454 million to the field over the next 10 years [103]. Meanwhile, Singapore's vast investment in its Biopolis complex (US$8 billion committed until 2010) continues to act as a magnet for Western stem cell scientists [104] and India has a rapidly evolving health biotechnology industry [4]. However, it is China, with its determination to muscle its way into the global stem cell market at all costs despite the legacy of its socialist economy, that poses the most intriguing political questions. Although its annual investment in stem cell research presently stands somewhere between US$4 and 10 million with 300 researchers working in 30 separate institutions, these figures are projected to increase dramatically [5].

Estimates quoted in the UK's Pattison Report suggest that, over the next 5 years, China's Ministry of Science and Technology (MOST – the main source of public research funds) is expected to spend between 500 million RMB (US$63 million) and 2 billion RMB (US$0.25 billion), depending on how productive the science turns out to be [105]. Clearly the intent is there, but does China have the political strategy to match the evident political will? (The reverse political question applies to the UK, where the issue is whether the political will is present to match the political strategy.) To what extent is the Chinese government able and prepared to construct the platform of policies required to facilitate its successful launch into the global stem cell bioeconomy? It may not have to follow the Pattison model slavishly, although it will presumably have to address its major strategic components.

We begin with the formal organization of China's R&D activities. How robust is this organization, what resources, in terms of both funding and scientific workforce, does it have at its disposal and what is its capacity to manage the necessary relationship between the basic and translational stem cell science? Second, what infrastructure is in place for the necessary engagement with the international financial markets of stem cells? What is the perceived contribution of intellectual property rights and venture capital to this aspect of the commercialization process? Third, what is the Chinese approach to the cultural implications of the new science? To what extent have issues of public trust in stem cell research (national or international) been addressed through ethical debate and regulatory reform? Finally, given this analysis, where should we position China as a political player on the global stage of stem cell science?

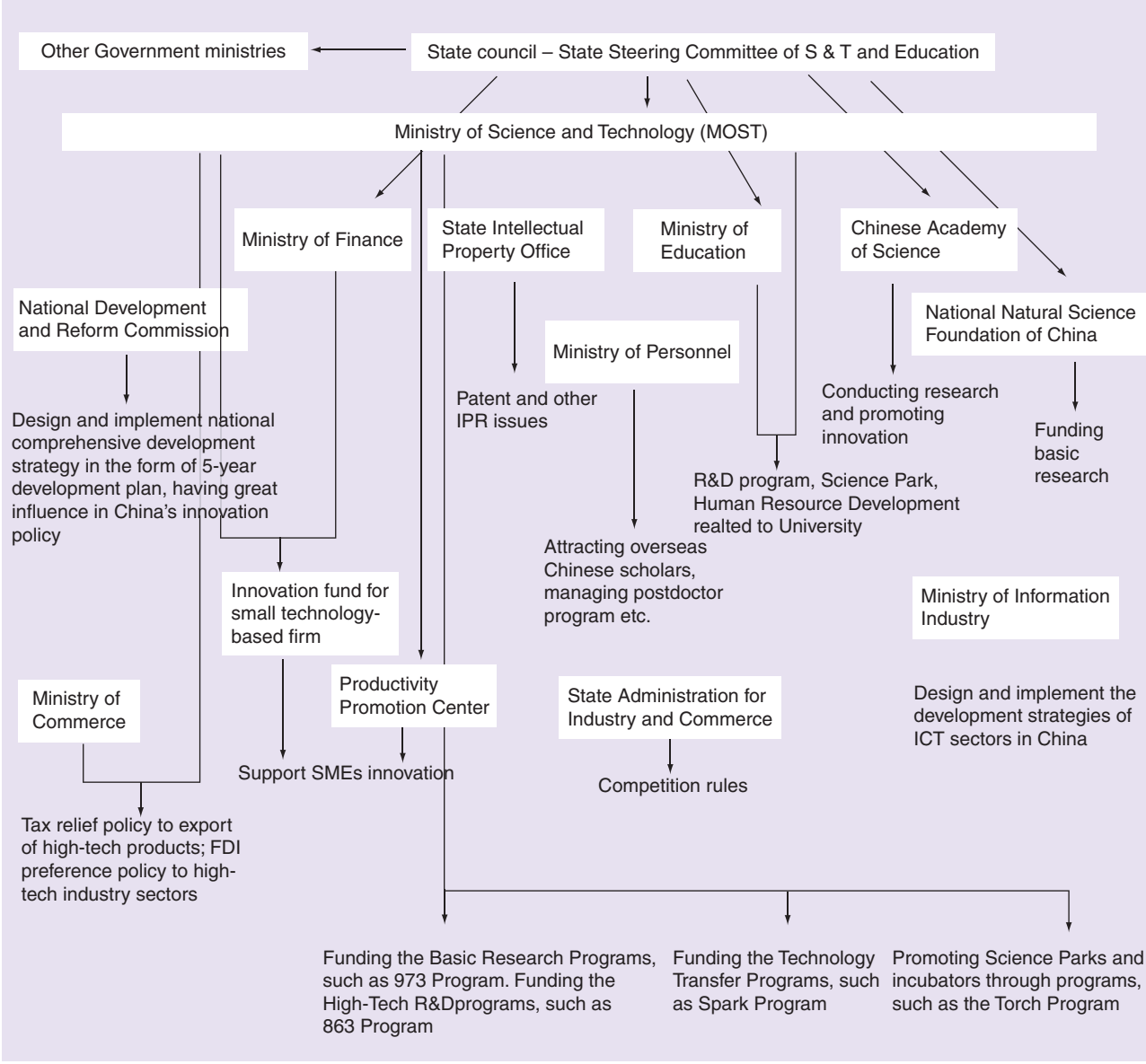
Organization, funding & workforce of R&D

Organization

China faces the problem common to most post-socialist countries of integrating its R&D system with an industry from which it has been historically detached [6]. At the general level of the State Council, its innovation policies are coordinated by the State (National) Steering Committee of Science and Technology (S&T) and Education, founded in 1998 (Figure 1). Propelled by this Committee, reforms of the R&D system have continued apace, as exemplified by the corporate restructuring of application-oriented research institutions affiliated with central and local government, the launch of the R&D Infrastructure and Platform Development Program in 2003 and the implementation of the National Medium and Long-term S&T Development Plan in 2006 [6,106]. The main, although not the sole, responsibility for the delivery of China's R&D policies lies with the MOST, which, in 1998, succeeded the State Science and Technology Commission. MOST has responsibility for a range of programs of basic and applied research, some of which have been running for over 20 years (Table 1) [7].

China's ambition of establishing itself as a leading presence in the world market was initially promulgated in 1986 through the High Technology R&D Program (the 863 Program), which identified both four major areas to be developed, of which biotechnology was one, and the infrastructure to service them. Under the auspices of MOST's predecessor, centralized research institutions were established and a comprehensive system of research governance introduced. However, the original 863 institutions were subsequently modified in ways that bring them closer to the US model of private–public alliances in the life sciences (even if the Chinese definition of a 'private' enterprise is notoriously loose) [8].

Figure 1. Chinese innovation policy institutions.



FDI: Foreign direct investment; ICT: Information and communication technology; R&D: Research and development; S&T: Science and technology; SME: Small and medium enterprises.

As early as 1988, reviewers of the program identified the centralized, top-down nature of Chinese research institutions and the lack of commercial incentive as a major obstacle to the translation of China's S&T capacities into marketable products. It was argued that scientists needed to be actively encouraged to leave the State sector and set up their own nongovernmental enterprises if Chinese S&T were to deliver on its commercial promises. A key policy intervention in support of this view was the Torch Plan of 1988, which aimed to decentralize R&D support by diversifying the funding base for nongovernmental organizations and linking their future development to that of high technology development zones.

The Torch Plan has had the effect of decentralizing the oversight of research directions and pushing for technical outcomes rather than results in basic science. It follows the specific mandate of supporting projects through the later stages of clinical development and, therefore, limits its funding to products that are capable of being scaled-up and standardized, as well as those technologies that demonstrate good commercial

Table 1. China's current science and technology programs.

Program	Initiating year	Objective
Key Technology R&D Program	1983	Concentrate resources on key and common technologies needed for industrial upgrading and socially sustainable development
State Key Laboratories Program	1984	Support selected laboratories at public or private facilities
Spark Program	1986	Support technology transfer to rural areas
National Natural Science Foundation of China	1986	Support basic research through directing funding of projects
High Technology R&D Program	1986	Enhance China's international competitiveness and its capability in high-technology R&D
National New Product Program	1988	Compile the annual list of new and high-technology products and fund those products selectively through grants and interest subsidy
Torch Program	1988	Support high-technology industry sector development through setting up science parks and incubators, funding projects and training
Key Basic Science R&D Program	1997	Support basic science research
Innovation Fund for Small Technology Based Firms	1999	Support the establishment of new technology-based firms

R&D: Research and development.
Data from [7].

prospects. The Torch Plan policy is not stipulated from the top-down by any state-level S&T program; nor does it receive a great deal of central funding. Rather, it acts as a 'fundraiser and broker', collecting and redistributing funds from various sources – in particular from state-owned banks. In this way, Torch Plan support plays much the same role as the venture capital market in the US.

Also within MOST's remit is the National Basic Research Program (the 973 Program), which was approved in June 1997 and, in its first 5 years, invested 2.5 billion RMB (US$ 0.3 billion), with individual projects receiving an average of 20–30 million RMB (US $2.5–3.8 million). The organizational structure of the program was designed to give project leaders more flexibility with the explicit aim of making it easier for them to employ 'high-level scientists from home and abroad' and providing 'a stage for the outstanding overseas Chinese people to return home to serve the motherland' [107]. Interestingly, even within this program, the Chinese government retains its emphasis on application, 'strategic' basic research and overcoming the perceived bias of scientific researchers towards 'emphasizing research while ignoring application' [107].

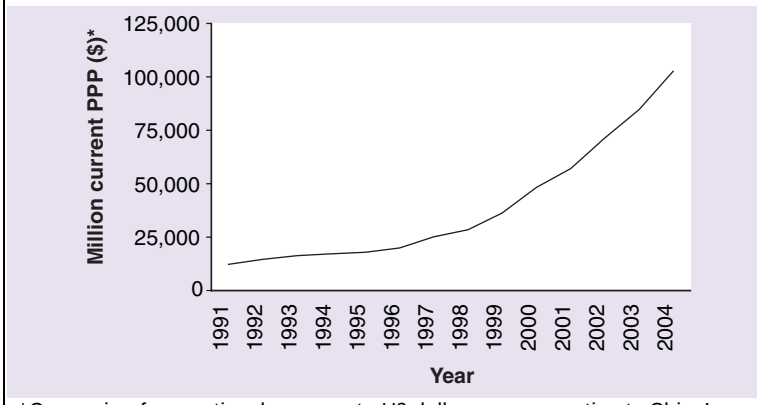
According to the most recent data available, in 2004, the 863 Program, the Key Technology R&D Program and the 973 Program were the three biggest MOST programs, constituting 72% of the MOST's total R&D funding allocation.

Although MOST controls eight of the nine R&D programs listed in Table 1, there are other sources of funding: some regional governments play a significant role and the Natural Science Foundation of China (NNSF) is a substantial source of funding for basic science (a third of the total basic science budget, ~2 billion RMD [US$0.25 billion in 2002]) that stands outside the MOST framework and reports to the State Council directly. In addition, on the provider side, the Chinese Academy of Sciences (CAS), founded in 1949 and based on the Soviet model of science in a planned economy, remains an important player in China's R&D structure. Some idea of the scale of CAS activity can be gained from the fact that, in 2005, it had 89 research institutions, one research-oriented university and a graduate school with 46,000 staff and 30,000 students. In 2004–2005 it generated 12,600 projects with a total expenditure of 9.3 billion RMB (US$1.2 billion) [108].

Funding

In its *Science, Technology and Industry Scoreboard 2005*, the Organization for Economic Cooperation and Development (OECD) highlights China's emergence as an international player. Overall expenditure on R&D in China has been rising steadily and it now spends more than any country except the USA and Japan (it is well ahead of individual EU Member States) (Figure 2).

Figure 2. China's gross domestic expenditure on R&D.

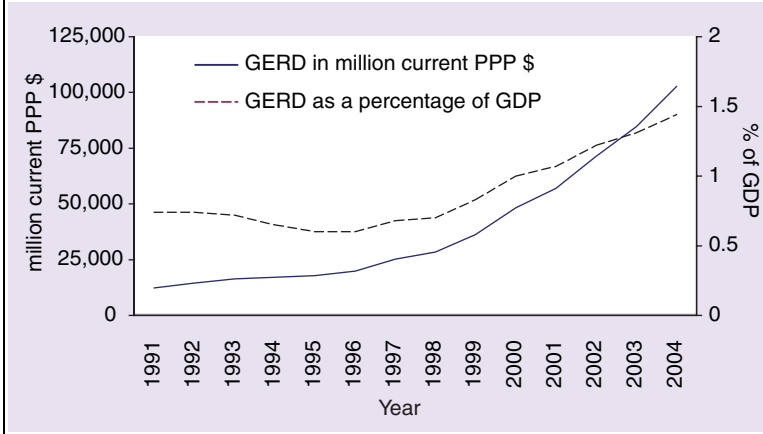


*Conversion from national currency to US dollars may overestimate China's R&D effort due to exchange rate intervention.

In part, the rapid growth in China's R&D expenditure is because it has more to spend as its gross domestic product (GDP) has risen rapidly. As a proportion of GDP, China's R&D expenditure is still relatively low (1.23% in 2004) compared with most developed countries. However, the Chinese government has recognized that there is both a need and room for it to increase the rate of its expansion of R&D spending. As a result, the percentage of GDP allocated to R&D expenditure has been rising steadily (Figure 3).

Within this expansion, continuing priority has been given to applied research and experimental development over basic research, with the result that the proportion spent on basic research is lower than in other countries (Figure 4).

Figure 3. China's gross domestic expenditure on R&D.



GDP: Gross domestic product; GERD: Gross domestic expenditure on R&D.

Workforce

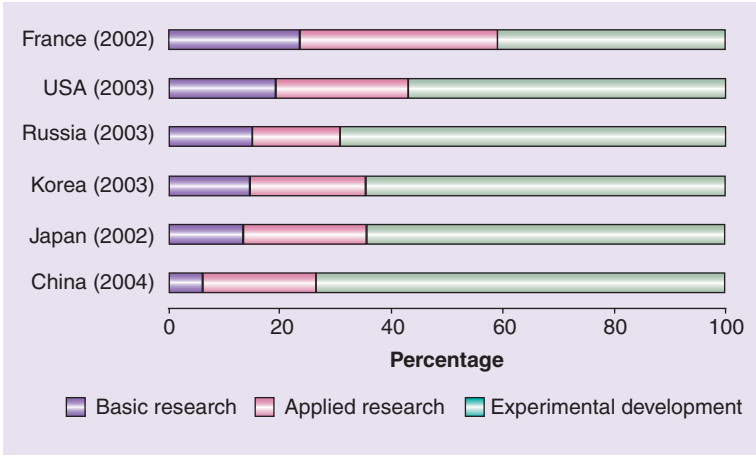
In terms of its scientific workforce, in 2003, China had 862,000 researchers, the second largest number in the world (Figure 5) [9].

However, the number of researchers in China has not grown as fast as its expenditure on R&D (Figure 6), 'largely due to researcher salaries which have risen very fast in recent years' [10]. This rise in salaries may be attributed, in part, to a recognition by the government that China's scientific workforce forms part of an international scientific labor market in which China is obliged to compete if it wishes to recruit and retain both its own and overseas scientists. It is also a reflection of the general improvement in the status and income of intellectuals and professionals in China over the past 10 years; the salary of those in the scientific research and technological service sector was the highest of the 16 sectors surveyed in 2000 [10]. In addition, scientists returning from overseas command approximately twice the standard salary of domestic Chinese scientists [109].

China's scientists are well networked and China–US ties are strong. In 2003–2004, China had the largest number of foreign scholars in the USA: 14,870 out of a total of 82,900 (18%) 'foreign scholars' conducting 'teaching or research' activities at 'US higher education institutions' [11]. US graduate training is increasingly important in the development of Chinese science. In 2001, US-awarded PhDs ran at 28.7 per 100 granted at home for Chinese students [12] (revealingly, the figure was only 1.5 for the UK). As one would expect, the Chinese presence in the USA is similarly high when measured in terms of educational outcome. In 2003, doctoral students from mainland China were awarded 2501 out of the total 9846 science and engineering doctorates awarded to foreign students in the USA.

The implications of this linkage are by no means entirely positive for China and may benefit the host nation more. Overall, China's Ministry of Personnel estimates that approximately 580,000 students have gone abroad since the late 1970s, with only approximately 160,000 (27%) returning [11]. In the USA between 1998 and 2001, over 60% of Chinese PhD students stayed after gaining their degrees. To put this in comparative perspective, the equivalent figure for South Korean PhD students was below 30% [13] (the Chinese stay rate was higher than that for either the UK or Canada and was only surpassed by India). These figures are highly significant for the development of health biotechnology in

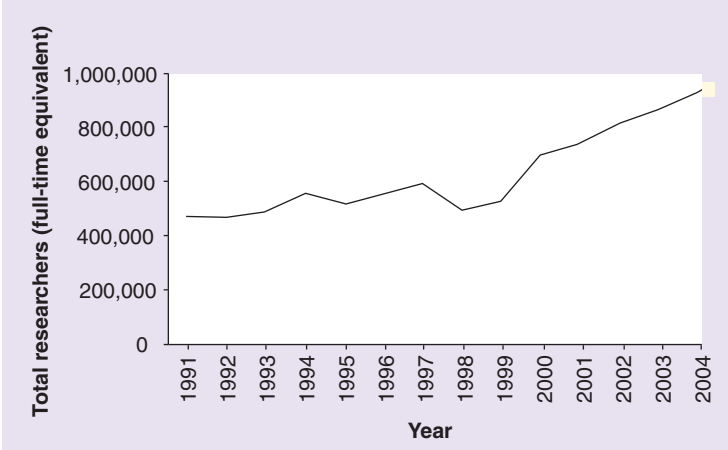
Figure 4. R&D expenditure by type of activity.



China; of the nearly 300,000 Chinese students overseas in 2004, a third were involved in the biotechnology field [14].

The Chinese government is well aware that if it is to develop its health biotechnology program, it must at least stem and preferably reverse this brain drain. Measures taken include salaries that are competitive in the international domain (particularly for top scientists), government financing for scientists who wish to set up laboratories in China, support programs and business incubators for entrepreneurs wishing to launch start-up companies and a special fund to finance the Chinese side of international S&T collaboration projects (100 million RMB [US $12.5 million] initially but can be increased as necessary) [107]. Two recent examples of initiatives taken to promote the inward flow of international scientists are the establishment of Beijing Life Sciences Research Institute (December 2005) and the China National Academic Centre for Biotechnology (May 2006).

Figure 5. Total researchers (full-time equivalent).



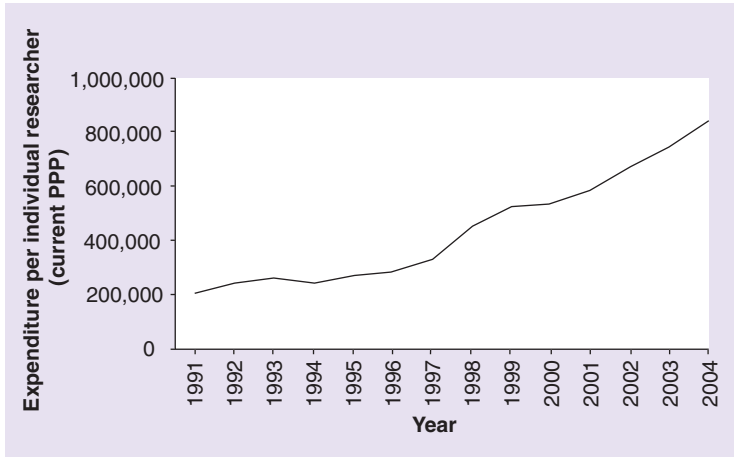
Stem cell science & the international market

China is working hard to reform its R&D infrastructure in ways that will enable it to compete effectively, if not become a world leader, in designated areas of health biotechnology. Since the late 1990s, MOST has targeted stem cell science and cloning as priority areas in its biotechnology portfolio, and development of the field has been intense. For example, in the field of basic science, the 973 Program has funded a number of projects. Out of a total of 31 projects currently listed under the general heading of 'Population and Health', the program has funded projects on 'stem cell research: basic science and clinic applications', 'differentiation of human embryonic germ cells and the plasticity of adult stem cells' and 'scientific research on fundamental issue of tissue engineering'. In addition, under the heading of 'Synthesis and Frontier Science', the program has funded research on 'mechanisms of nonhuman primate somatic nuclear transfer and therapeutic cloning' [110].

Venture capital

To be effective, China's political strategy on stem cell science must incorporate the needs of external markets and communities as well as changes to the internal R&D infrastructure. In particular, without a venture capital input to the development process, China will find it very difficult to turn the results of its basic and translational stem cell science into 'commercially successful' therapeutic products. Although its policy on foreign direct investment (FDI) has been successful (in 2002, China became the world's largest recipient of FDI, receiving nearly $53 billion [15]), attracting foreign venture capital has proved much more problematic. To an extent, the emergence of China's venture capital market has been impeded by uncertainties surrounding its legal environment, corporate governance arrangements and economic policy (the lack of currency convertibility is clearly a problem). At present, China does not have a specific law to regulate venture capital development but simply a Company Law and joint regulation by seven ministries, although this is likely to change soon.

Figure 6. Expenditure per individual researcher (current PPP $)



However, most important is the lack of 'exit options' for Chinese enterprises. Venture capitalists are in the high-risk business of investing in emerging technologies and markets; thus, they do not expect to stay invested once businesses have matured. Unfortunately, in China, there are relatively limited opportunities to exit investments.

China's stock exchange remains weak. It is thinly traded and therefore illiquid, making flotations (especially initial public offerings) very difficult. The Hong Kong market is stronger, but the Growth Enterprise Market (GEM), Hong Kong's 'second-board' for emerging technology stocks (similar to the NASDAQ) has been a very poor performer. Given the problems with the GEM, it is perhaps not surprising that the mainland government appears reluctant to open the long-promised second board in Shanghai, although there is a medium and small enterprise board in Shenzhen. Even if the government did set up a NASDAQ-type exchange in Shanghai, the existence of such a market does not solve the problem alone. Venture capitalists can only be sure of exiting their investments where there are well regulated, relatively liquid markets. Back in the heady days of the dot-com boom, several Chinese internet ventures were listed on the US NASDAQ, however those that did list performed very poorly. In the current climate, an overseas listing is not a realistic exit option for venture capital investments in Chinese biotechnology.

However, whilst the lack of exit strategies will make China a less attractive option for the conventional (US) model of venture capital, there may be domestic alternatives. China has evolved a number of types of venture capital firms. National and, more importantly, local and provincial governments, have played a significant role in the development of this public venture capital scene. Perhaps now aware of the problem, the national government appears to be increasing its role, as witnessed by the recent loan by the China Development Bank to MOST [105]. In addition, there are corporate, university and foreign-owned venture capital firms and hybrids formed by joint ventures between different types of firms [16]. Unusual business models are emerging in response to the idiosyncrasies of the Chinese economy.

One such example is the Union Stem Cell and Gene Engineering Company Ltd (StemGene). It was incorporated in February 2001 with two principal shareholders: the Institute of Haematology in Tianjin and the Shanghai Met Corp, an organization involved in the import and export of textiles. The company was floated on the Shanghai Stock Exchange, raising US$30 million. It does not fund stem cell research directly but finances the building of a new hospital that will, in turn, generate revenue for the research [111]. The China National Academic Centre for Biotechnology is another example. The Beijing International Trust and Investment Co. Ltd is to invest US$160 million in the center over 3 years, with the goal of nurturing 100 companies and up to 500 research laboratories to facilitate the exploitation of Chinese technologies [17]. The press release makes it clear that 'Within the service functional area [of the Centre], domestic and foreign agencies of venture capital investment, intellectual property rights and technology transfer relating to biotechnology and bioindustry will get together to provide comprehensive services to the development of biotech enterprises [112]'.

Intellectual property rights

The presence of intellectual property rights (IPR) in the above statement is not a coincidence. Without the appropriate patenting framework, ownership of a scientific product cannot be assured, the present and future value of the product cannot be ascribed and investors will not invest their capital if a return is either not possible or dubious (the current debate at the European Patent Office [EPO] regarding the patentability of human embryonic stem cells indicates how unstable this aspect of the development of the science can become [113]).

A patent office was established in China in 1980 and it was accepted as a member of the World Intellectual Property Organization (WIPO) in the

same year. A Patent Law was introduced in 1985 and, with its accession to the World Trade Organization (WTO) in 2001, China agreed to conform to the requirements of the Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement [18]. Since then, China has cooperated frequently with WIPO and the EPO on personnel training and promoted IPR teaching and research in over 70 universities [17]. However, it remains unclear precisely how far the necessary respect for intellectual property is now thoroughly embedded in Chinese culture and economic behavior, given its history of international piracy in IPR (second highest after Vietnam) [17]. On the other side of the coin, it can also be claimed that China's wealth in bioresources exposes it to biopiracy by developed countries. For this reason, the Patent Law was amended in 2002 to restrict the commercialization of sensitive human biological material [11].

Certainly, there has been a dramatic rise in the amount of patenting in China over the past 10 years. The number of patents granted by the State Intellectual Property Office has more than doubled, rising from approximately 43,000 in 1994 to 190,000 in 2004. Meanwhile, the number of patent applications has risen fourfold, from approximately 78,000 in 1994 to 354,000 a 10 years later [114]. However, when compared with other countries, China has made very few applications to the EPO, the US Patent and Trademark Office (USPTO) and the Japanese Patent Office (JPO), and clearly will not be able to develop its global R&D potential until it seriously improves its position in this area [19].

IPR protection is, of course, very important to the international pharmaceutical industry, without whose commitment any new health biotechnology sector is unlikely to take off. Thus, it is interesting to note that almost 24,000 intellectual property cases were adjudicated between 1998 and 2002, signaling to the biopharmaceutical firms 'China's seriousness in protecting IP' [20]. Leading pharmas have already established a presence in China – Glaxo SmithKline China (Beijing), Pfizer Pharmaceuticals (Beijing), Novartis Pharmaceutical (Beijing) and Merck China (Shanghai). China has more than 150 health biotechnology products in clinical trials and is increasing the number of health biotechnology patents by approximately 30% per year [20].

Regulation

The UK's Pattison Report on stem cells places considerable emphasis on the importance of regulation in its model of how the government should support and facilitate the development of stem cell science and its commercial applications. Regulation provides protection, not only for the public against the potential invasions of an over-zealous science, but also for the state against accusations that it has failed in its duty towards its citizens. No political strategy for stem cell science should be without it.

Current regulation

As the Hwang affair in South Korea has vividly illustrated, regulation has an international political significance. Regulatory problems in one country can rapidly ripple through the international community of stem cell science to cause difficulties in another. There may be a decline of trust in some stem cell scientists, not only on the part of the public but also on the part of fellow scientists. Since the advance of stem cell science is increasingly dependent on international collaborations, the possibility of such a decline with reference to a particular country means that its scientific community may find itself hampered, if not isolated, in its relations with fellow scientists in other parts of the globe.

The optimistic view is that, since China has accepted the main relevant international declarations and guidelines in bioethics, that 'these documents [then] form the basis for domestic biopolicy making and for engaging in the global markets' [21]. Thus, for example, China co-authored the World Health Organization's (WHO's) *Guidelines on Ethics in Medical Genetics* (1998), the United Nation's Educational, Cultural And Scientific Organization's (UNESCO's) *Universal Declaration on Human Rights and Biomedicine* (1998) and UNESCO's International Bioethics Committee's (IBC's) statement on *Human Embryo Research and International Solidarity and Cooperation* (2001). They endorsed the World Medical Association's (WMA's) Helsinki Declaration on *Ethical Principles for Medical Research Involving Human Subjects* (2000) and supported a UN ban on human cloning for reproductive purposes. However, as with all international policy making, there is always likely to be a gap between its formation and its domestic implementation. In China's case, the historic absence of a developed infrastructure of bioethical controls renders that likelihood all the greater.

In December 2003, the MOST and the Ministry of Health (MOH) jointly issued the *Ethical Guiding Principles on Human Embryonic Stem Cell Research* [105]. The guidelines cover stem cells derived from ordinary human embryos as well as those from human embryos cloned from somatic

cells, human fetuses and those generated by parthenogenesis. In common with the UK's framework, the guidelines:

- Prohibit reproductive cloning but permit therapeutic cloning;
- Permit stem cell experimentation on human embryos up to 14 days old but forbid experimentation on older embryos;
- Rule that all gametes and tissues must be voluntarily donated in accordance with the principle of informed consent and that research institutions proposing to experiment with human embryonic stem cells (ESCs) must establish an ethical committee to review the research;
- Prohibit the implantation of human embryos used in stem cell research;
- Prohibit the buying and selling of human eggs, sperm, embryos and fetal tissue.

However, if these guidelines are to have lasting political credibility, they must not only be implemented but, so far as the international scientific community is concerned, be seen to be implemented. And herein lies the rub. For at the moment, China's regulatory approach is based on guidelines, not state legislation. There is no licensing system for ESC research, no infrastructure of monitoring and inspection, limited ethical expertise at the individual institutional level and no visible set of penalties for noncompliance. In any case, not all human ESC research is funded by the Ministries (MOST and MOH) that are sponsoring these guidelines [115].

Furthermore, for regulatory purposes, these Ministries do not always work together. The supply side of human ESC research (oocytes, embryos and sperm) fall within the egis of the MOH, not the MOST. In October 2003, the MOH introduced three new administrative regulations on reproductive medicine that set out the ethical principles governing assisted reproductive technology (ART) and human sperm bank management. The creation of embryos is dealt with in detail. Superstimulation, as opposed to therapeutic stimulation, of the ovaries is forbidden and informed consent must be obtained from the donor. Embryos are created solely for the purpose of procreation but 'leftovers' may be donated for medical research, again on the basis of informed consent from the donor. However, whilst the regulations prohibit, among other things, the use of the technique of human egg nucleus transfer for infertility treatment (cloning) in clinical treatment (*in vivo*), they do not cover basic research *in vitro*, since this falls under the authority of the MOST [23]. And again, there is a problem of policy implementation. The 2003 regulations were a response to a government survey in 2001 showing numerous examples of *in vitro* fertilization centers operating without the appropriate license [21].

Emerging issues

All regulatory systems must evolve if they are to keep pace with changes in a science and the possibilities its progress generates. In May 2006, Suzie Leather, the chief executive of the UK's Human Fertilisation and Embryology Authority (HFEA), announced a public consultation on human egg donation. She commented: 'The Authority today heard that there are international concerns that could limit the potential of research if there were concerns about how eggs are donated' [116]. As the science of human ESCs expands, there is an increasing demand for oocytes and embryos, which raises political questions, as the Hwang case again illustrates, regarding what ethical standards, if any, govern their supply.

It is commonly supposed that the supply of 'fresh eggs and embryos' in China is plentiful (although not all Chinese scientists have found it so [117]) and that the population, accustomed as it is to the rigors of state population control through abortion (including enforced sterilization in rural areas), places little value on the early human embryo and fetus [5,118]. The state, meanwhile, through its one-birth policy, has become accustomed to a policy approach that 'relocated gender difference in reproductive physiology and placed women within the domain of the state, to be mobilized in the service of its reproductive or productive agendas' [22]. So there emerges the possibility of a state apparatus being harnessed to the needs of an expanding science, perhaps fuelled by international pressures, with the goal of ensuring a reliable supply of the appropriate research material.

This, in turn, should be placed in the context of China being increasingly seen by the global pharmaceutical industry and its suppliers as a target for tissue sourcing, clinical trials and biomedical services. Over the past few years, the US and European pharmaceutical industry has made moves to outsource clinical trials to specialized research service providers, which in turn have relocated the actual conduct of trials to countries such as India and China where the clinical labour (patients) is plentiful and inexpensive [24]. Between 1995 and 1999, the number of international human subjects involved in clinical trials grew a hundredfold, from 4000 to 400,000, and the number of clinical trial investigators conducting multinational drug

research in low-income settings increased sixteenfold between 1995 and 2005 [25]. In China, this expansion in the use of its population has outstripped its regulatory capacity and led to situations, such as occurred in the Anhui province, where the adherence 'of foreign researchers' to the basic ethical principles of informed consent has become questionable [28].

Given that Chinese medical scientists are already engaged in providing experimental stem cell therapy for spinal injuries, ataxia, stroke, brain injury and cerebral palsy (sometimes with the explicit admission that their clinical experiments have no clear theoretical basis and would not meet Western ethical standards [119]), the need for a robust regulatory apparatus that can cope with the rising international demand for both treatments and research collaborations is self evident [120]. For example, Wise Young, Director of Rutgers University's WM Keck Center for Collaborative Neuroscience in Piscataway (NJ, USA), and an internationally recognized American expert in spinal cord injury, is spearheading a new project to conduct clinical trials using stem cells in China and has set up a network of Chinese hospitals to test new treatments for spinal cord injury. His view is that 'the availability of the enormous Chinese population will drastically speed up the clinical trial process, allowing new therapies to be tested more quickly and cheaply'. He hopes 'the network will ultimately provide a go-to testing site for large pharmaceutical companies with new spinal cord injury treatments' [121].

Conclusions

Unlike the UK, China does not have a single political strategy on stem cell science but rather a series of separate policy initiatives that, taken together, mean that it is fast becoming an important player in the global stem cell arena. State investment and political commitment are undoubtedly there. Furthermore, China's R&D framework is perfectly capable of taking the science forward, providing it can gain the international collaboration necessary to support both its basic science and the development costs of the long haul to therapeutic product (although a number of mixed commercial models are in use, e.g., the aforementioned Stemgene example, there is little evidence that the Chinese have considered models where the nontherapeutic qualities of stem cells, such as drug screen assays, disease modeling or toxicity testing are used as intermediate platforms to sustain investor interest [122]).

The Minister for Science and Technology, Xu Guanha, has expressly recognized China's basic research is weak and requires international support if it is to maximize the results from its scientific investment [123]. Clearly, the international scientific networks are there, particularly in the form of China–USA ties. However, China's laissez-faire approach to the overseas training of its scientists has so far meant that more scientists remain abroad than return after the completion of their training. Although part of the answer to this anomaly is financial incentives, a broader issue is the infrastructure available in China to scientists with international ambitions. This is not just a matter of state investment in stem cell research but also the availability of a venture capital market, appropriate patenting arrangements and an interested pharmaceutical presence.

At present, the injection of foreign venture capital to support the small biotech firms and university spin-off companies necessary for the commercialization of stem cells has to be organized in a highly creative fashion to circumvent the residual effects of the planned economy, the weak stock exchange and the consequently limited exit options for investors. Access to, and interaction with, the international finance market will be aided by a more positive approach to patenting as a significant part of the commercialization of stem cell science. As the Minister for Science and Technology also pointed out, 'the ratio of inventions to patent applications is still insignificant' [123].

Nor is it clear that the big pharmas are entirely confident that China will prove a satisfactory destination for future investment. Despite the argument advanced by some commentators that China is a territory about to be annexed by the forces of Western imperialism in the form of multinational pharmaceutical corporations, it remains the case that Chinese drug approvals are relatively slow and inefficient, a bureaucratic legacy of yester-year [124]. One view is that of Hai Mi, Senior Director of strategic planning for Wu Xi Pharma Tech in Shanghai, who observed that the State FDA (SFDA) may be so slow in approving clinical trials that they end up being more expensive than in the West. "The SFDA is a bottleneck and it has to change considerably for the industry to take off in China", he commented [27].

But probably most important, in terms of China's future political strategy, is its approach to public trust in stem cells – national and international. The recent furor in May 2006 surrounding accusations of scientific misconduct in China shows only too clearly the political penalties of not

having a robust system of regulation and scientific governance in place [28]. In the absence of such a system, and the reported lack of confidence in China's existing ethics and investigating committees, the Internet has become the alternative means for the discussion of ethical concerns [125,126]. As the South Korean case demonstrated, once the cat is out of the ethical bag, the impact on global scientific and public opinion is likely to be considerable.

There is ample political space for the inadequacies of China's stem cell regulation to be exposed. For example, China's supposedly liberal environment for the supply and collection of the materials necessary for human ESC research (oocytes, embryos and fetal tissue) may in fact be a passive (rather than a positive) product of a political culture where open public debate has been discouraged historically. Social research on attitudes to abortion among the Chinese population indicates that the human embryo does not necessarily have the low status generally assumed by Western observers [29]. Rather, it is probable that there is a pluralism of views informed by a variety of ideological and philosophical traditions. At present, the political manifestation of such cultural attitudes is limited by the absence of formal mechanisms for the public discussion of scientific advance and most debate takes place in the confined professional realms of scientists and bioethicists. However, this is unlikely to remain the case as the international linkages necessary for China's development grow. The maintenance of domestic trust in new sciences, such as stem cells, will then become an issue to which international pharmaceutical firms, venture capital investors and foreign scientists will require a political answer.

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Executive summary

Political question

- China has the ambition to become a major force in the global stem cell bioeconomy and is committed to spending between US$63 and US$250 million on stem cell science over the next 5 years. To what extent does it have the political strategy to match this ambition?

Organization, funding and workforce of R&D

- China faces the problem common to most postsocialist countries of integrating its research and development (R&D) system with an industry from which it has been historically detached.
- The majority of R&D programs are controlled by the Ministry of Science and Technology (MOST), with some regional governments playing a significant role and the Natural Science Foundation of China acting as a substantial source of funding for basic science.
- Expenditure on R&D has been rising steadily, although is still relatively low compared with most developed countries.
- China has the second largest scientific workforce in the world but it suffers from a brain drain, particularly to the USA.

Stem cell science & the international market

- The emergence of a venture capital market capable of supporting the development of stem cell science has been impeded by the lack of exit options for investors. However, national and local government support is beginning to produce some uniquely Chinese business models for the use of venture capital.
- The protection of intellectual property rights within China is improving, although Chinese scientists make very few applications to the European Patent Office, the US Patent and Trademark Office and the Japanese Patent Office and, therefore, lack a global patenting presence.

Regulation

- China has accepted the main relevant international declarations and guidelines on bioethics and the MOST and the Ministry of Health have jointly issued ethical guidelines on human embryonic stem cell (ESC) research. However, there is no licensing system for ESC research and no infrastructure of monitoring and inspection.
- China faces emerging regulatory issues regarding the use of oocytes and embryos in stem cell research and the outsourcing to China of clinical trials by foreign pharmaceuticals and researchers.

Conclusion

- China does not have a single political strategy but a series of separate policy initiatives that together make it a global player in stem cell research.
- As the Hwang case in South Korea has demonstrated, international public trust is a requirement for the national development of stem cell science. For the future, China must address this requirement through the implementation of fresh regulatory and ethical policies if it is to realize its global ambitions in this field.

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