Nesta

CHINA'S ABSORPTIVE STATE

Research, innovation and the prospects for China-UK collaboration

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October 2013

UK Science & Innovation Network

Department for Business Innovation & Skills

RESEARCH COUNCILS UK

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CONTENTS

FOREWORD

Will China lead? Or will it follow? For much of human history China led the world in science and technology. Western stereotypes of a backward and unchanging China obscured much more of that history than they illuminated. Indeed as the historian Joseph Needham showed in his extraordinary accounts, Chinese scientific civilisation was rich, and dynamic in many fields.

Yet during and after the industrial revolution China slipped far behind. It is only in the last few decades that it has once again caught up. Now, as this report makes clear, change is happening very fast. But the picture is complex. It's true that China has primarily excelled at adopting technologies from elsewhere, as a 'fast follower' rather than a leader. But in some fields it is on the frontier of technological knowledge, and the growth of published research is extraordinary. It's true that China remains highly dependent on connections to pioneers elsewhere in the world – and is lower down the global value chains than it would like. But its own capacity is developing fast, with 25 per cent of the world's R&D workforce and many Chinese multinationals now high in league tables of research spending and results.

As this report shows, a distinctively Chinese approach to innovation can now be seen in many sectors. It involves not only absorbing the best ideas from around the world but also recasting them and recombining them through 're–innovation'. Some of that is the result of classic R&D. But much involves what Nesta has called 'hidden innovation' – the innovation in design, processes and organisational models in manufacturing and services which isn't captured by the traditional measures of R&D.

This is an important report for Nesta. Over the last few years we have been doing more to map 'innovations in innovation' around the world. In technology as in so many other things, we live in a multipolar world and it's no longer enough to learn from familiar places like Silicon Valley or the German industrial heartlands. That's why we have developed partnerships not just in China but also in India, Brazil, the US, Europe and elsewhere.

Continuous innovation in innovation is a response to the diminishing returns that seem to afflict any tool used to accelerate the creation and spread of ideas. What worked in one era to create new pharmaceuticals or transfer technology out of universities, may not work so well 20 years later. So policymakers, just like businesses, have no choice but to constantly renew and reinvent their methods, and the ones that are agile and fast to learn from others, are the ones that will succeed.

The other imperative described in this report is partnership – becoming better at collaboration for mutual advantage. The UK has now overtaken Japan to become second only to the US in the number of its joint research publications with China. Some of what is happening in China is challenging to the UK and others. It means tougher competition. But there will also be many new opportunities for collaboration. This report sets out a road map for making the most of them.

Geoff Mulgan
Chief Executive, Nesta

ACKNOWLEDGEMENTS

We would like to thank the project partners – The Foreign Office–BIS Science and Innovation Network, RCUK China and the Department of Business, Innovation and Skills– for their financial contributions and input throughout the project, particularly Sam Myers, Morag Brown, Frazer Macdonald, Alicia Greated, Grace Lang and Nick Rousseau.

Special thanks go to the teams in Beijing for helping to organise workshops and meetings: Mary Li, Katy Fu and Will Hellon. In China and the UK, we are very grateful to the interviewees and expert workshop participants who generously gave their time, expertise and insights for the project. They are all named in the Appendix. For research support we would like to thank Joy Yeh, Chrysa Glystra and Mads Neumann. Thanks to Karen Gurney at Thomson Reuters for her support with the bibliometrics research specially commissioned for this report. Thanks to Lulu Pinney for her excellent data visualisation. Thanks to Tom Duke, Cong Cao, Philip Shapira, Adam Segal, Xiaolan Fu, Mu Rongping, Dan Breznitz and Nesta staff members Stian Westlake, Louise Marston, Liam Collins, Albert Bravo–Biosca and Geoff Mulgan for their comments on the draft. The views expressed in this report are those of the authors and do not necessarily reflect those of the project partners.

EXECUTIVE SUMMARY

A great deal of speculation surrounds China's prospects in science and innovation, as with other aspects of China's development and heightened visibility on the global stage. The same pitfalls – of hype, generalisation and only partial awareness of the domestic political, economic and cultural context – mean that discussion of this topic in Europe and the US can sometimes obscure as much as it illuminates.

China's innovation system is advancing so rapidly in multiple directions that the UK needs to develop a more ambitious and tailored strategy, able to maximise opportunities and minimise risks across the diversity of its innovation links to China. For the UK, the choice is not whether to engage more deeply with the Chinese system, but how.

Innovation is caught up in a bigger unfolding debate about the pace, scale and direction of China's economic and political reforms. Much still depends upon the playing out of a set of tensions: between the planned economy and the market; national and global priorities; the hardware of research infrastructure and the software of culture and ethics; the skills and creativity of home–grown talent, and the entrepreneurialism and networks of returnees. In the decades to come, China is likely to change innovation just as much as innovation changes China.

Our report

This report analyses the policies, prospects and dilemmas for Chinese research and innovation over the next decade. It is designed to inform a more strategic approach to supporting China–UK collaboration. With the recent once in a decade leadership transition, and a review of China's Medium and Long–term National Plan for Science and Technology Development 2006–2020 (MLP) now underway, Nesta and its partners – the UK's Department for Business Innovation and Skills, the Foreign Office – BIS Science and Innovation Network and Research Councils UK – were keen to review how China's innovation system has changed over recent years.

To do this, we analysed over 600 policy documents, reports, statistical digests and articles (in English and Chinese) to capture the current state of knowledge, scholarship and debate. We commissioned new data from Thomson Reuters to shed light on the health of UK–China collaborative research. We held three expert workshops in London and Beijing. We also carried out in–depth interviews with experts and stakeholders across government, academia, SMEs and multinational corporations in the UK and China as well as Germany, Australia and the US.

Ten key findings

1. **China is an absorptive state, increasingly adept at attracting and profiting from global knowledge and networks.** China's growing innovation system has succeeded in combining rapidly improving home–grown capabilities and infrastructure with foreign technologies and knowledge to build the world's fastest supercomputer, send astronauts into space and pioneer the Beidou Satellite Navigation System. These examples suggest that what China's President Xi Jinping terms *"innovation with Chinese characteristics"* will not be a straightforward path from imported to home–grown innovation, but a messier process in which the lines between Chinese and non–Chinese ideas, technologies and capabilities are harder to draw.

   Characterising China as an absorptive state helps us to understand its current phase of development: that the systemic conditions for research and innovation have reached a stage where ideas can be effectively absorbed and exploited, with increasingly dense and targeted networks to enable this. But it also helps us assess the prospects for future development: absorption will remain a core strand of national research and innovation policy, and Chinese firms' impressive ability to rapidly absorb and re–innovate, while adding novelty and value to ideas and technologies in the process, is crucial to understanding their competitiveness.

2. **Accelerating the shift to a more innovative economy remains a core priority of China's new leadership, yet equally important is a new focus on quality, efficiency and evaluation.** A policy focus since the early 1990s on investment and growth has propelled China into the top ranks of global innovation, but the process has been inefficient and these policies are now being complemented by a growing focus on efficiency, quality, coordination and evaluation. This trajectory of reform is likely to be consolidated in the 2016 13th Five Year Plan.

3. **The exceptional growth trajectory of China's research base continues, but has not yet been matched by similar leaps in quality.** Growth in output is pervasive throughout the system, both in large fields such as engineering and in newer fields such as biomaterials, which grew 15–fold in the last decade. Impact remains below world average in most areas, but is close to that benchmark in a number of fields, including engineering and mathematics, and consistently above average in agriculture. The strengths of established research economies like the UK are relatively stable from year to year, while China's are changing at an unprecedented rate. This requires a cautious approach to interpreting strengths and weaknesses. Spikes of excellence and pools of mediocrity can be hidden among the averages.

4. **Research and innovation is still highly concentrated on China's east coast, but diverse models of innovation are visible among east coast hotspots.** While some second tier inland cities such as Chengdu and Wuhan have benefited from government and multinational investment in innovation, well over two–thirds of all patents were granted to applicants on the east coast in 2011. In addition, the east coast accounted for over 60 per cent of China's publication output. Yet among the eastern hotspots of Beijing, Shanghai and Guangzhou, there are contrasting innovation models. While the central government sets the overall policy context, targets and evaluation metrics, there is a considerable degree of autonomy in how to deliver on these goals in different places, leading to experimentation through different interpretations of national policies.

5. **Over the last five years, an expanding tier of Chinese multinationals have become visible in global rankings of firm–level innovation.** Both Baidu and Tencent appear in the top 50 of *Forbes'* list of most innovative companies and ZTE applied for more PCT patents than any other company in the world in 2012. China has benefited considerably from the fragmentation and modularisation of global production, which has allowed its enterprises to specialise within particular niches of product and service value chains. Businesses are responsible for almost three–quarters of China's R&D spend, but progress towards an enterprise–led innovation system has been inhibited by the slow pace of reform in state–owned enterprises.

6. **Previously regarded as a weakness, the quality and speed of China's capacity for incremental re–innovation is now an important competitive asset.** Sophisticated manufacturing networks excel in absorbing, adapting, prototyping and market testing new products and technologies at speed. 'Shanzhai' methods of production previously referred only to substandard imitation, but as former shanzhai companies have developed disruptive products, this method of innovation is of growing international interest as a distinctive way of adding value. These approaches are not only prevalent in manufacturing, but also in the digital and creative industries.

7. **After three decades of rapid economic growth, debate in China is intensifying about how to direct innovation towards social and environmental goals.** Environmental and health concerns are prompting a sharper focus on low–carbon and sustainable innovation and the government is investing heavily in low–carbon cities, renewable energy and energy efficiency programmes. A more proactive and vocal civil society is at the forefront of growing calls for social innovation. More demanding Chinese consumers are driving new types of user–driven innovation, a process which will intensify as domestic consumption takes over from investment as the main driver of China's economic growth.

8. **Our new analysis shows that in 2011, the UK overtook Japan to become second only to the US in the number of its joint research publications with China.** The UK has increased its share of China's collaborative activity while other EU countries have declined. This is an encouraging sign but a weak predictor of future performance, owing to the speed of change within the Chinese system. For any country seeking to collaborate with China, ensuring a density and diversity of connections will be crucial, spanning the academic, research, commercial, trade and cultural spheres.

9. **There is no perfect formula for high impact collaborations with China.** There is very little evidence available on the effectiveness and economic impact of different models of support for international innovation collaboration. Each county's strengths and modes of engagement are unique, and while it is important to monitor and benchmark the UK's performance against that of other countries, and learn from other countries' experiences, the transfer of 'best practices' in collaboration is rarely straightforward. For instance the US and German approaches to collaborating with China are frequently held up as models for the UK to emulate. However, the UK's economy and military might is substantially different from that of the US and its manufacturing base contrasts with the one which forms the foundation of the Sino-German relationship.

10. **The greatest 'China risk' for innovative companies is focussing too heavily on downside risks, and missing out on the opportunities that China presents.** Hawkish perspectives on Chinese innovation highlight the 'dark side' of China's absorptive state: international flows of ideas and technology resulting from IP theft, forced technology transfer and hacking. But innovative firms recognise that without some risk, there is little reward. Intellectual property is only as valuable as one's capacity to exploit it and stay ahead of the competition. The increasingly absorptive Chinese system brings both risks and opportunities for businesses, universities and others seeking to work with and in China. These risks need to be managed with care, but they should not be over–emphasised to the extent that they eclipse a far greater risk – that of failing to participate fully and benefit from the next phase of China's growth.

Recommendations

1. **The UK should develop a new five–year strategy for China–UK collaboration in research and innovation.**

   Work towards this strategy should begin now, but 2016 would be the ideal time to publish it, to take account of new policies in China's 13th FYP, and the 2015 post–election Spending Review in the UK. The strategy should encompass the full breadth of potential innovation links between the two systems, from research through to the commercialisation, demonstration and scaling phases of new technologies. Some programmes should envisage a horizon of decades rather than years, and this strategy should be fully embedded in a long–term plan for innovation–led economic growth in the UK. Stable long-term investments and incentives should help experimental approaches to collaboration flourish. On the UK side, this process will require the active involvement of the Technology Strategy Board and a wide range of industrial and business partners in addition to BIS and RCUK.

2. **The UK should develop more sophisticated methods and metrics for identifying China–UK innovation opportunities and for evaluating impact.**

   The strategy should look beyond readily measurable research performance and patenting data to understand China's evolving specialisms. It should explore how UK companies can better engage with China's strengths in developing, iterating and scaling technologies. The UK should develop approaches to supporting ecosystems of collaboration rather than individual companies. The UK's 'eight great technologies' should form the basis of a mapping exercise to determine specific China–UK complementarities, which should feed into the five–year strategy. Bibliometric data should be used to expand and diversify research collaborations, by developing a real–time data resource for UK researchers, identifying the range of Chinese universities where they can find relevant capacity and competence. One of the strengths of UK innovation policy is the high degree of openness and debate about the effectiveness of different approaches. Much equivalent debate and analysis takes place on the Chinese side, but is often difficult to access online. The UK government should encourage Chinese counterparts to promote access to data and analysis on innovation policy in the same way the UK has on the gov.uk website.

3. Expand the China–UK innovation policy dialogue to include a new bilateral expert group, able to undertake in–depth analysis to inform ministerial meetings.

China and the UK should expand their existing innovation policy dialogue to establish a group of Chinese and UK experts in research, innovation and industrial policy, able to explore themes relevant to collaboration and provide input and advice to official discussions. This group could analyse emerging policies and what they mean for each country, evaluate programmes and methods used to support collaboration, and assess Chinese and UK strengths and weaknesses for areas of complementarity. Crucially, the work of the group should be published, to inform public debate on UK–China collaboration. Focused analysis could also be undertaken under priority themes spanning research and innovation, for example:

- Ageing and healthcare: Both countries face the challenge of caring for an expanding elderly population with a dwindling workforce. Innovations in health technology, and systemic approaches to transformation could be explored.

- Smart and sustainable cities: China has been investing heavily in smart and eco–cities, and efforts have been made to match Chinese demand to UK strengths in design, construction and big data. But this is an area that can only grow in importance given the pace of urbanisation in China and Chinese excellence in materials science and engineering.

- Creative industries: China is now making significant investments in cultural institutions and creative industries, and is a huge potential market for the UK. Creative industries are an area of great strength for UK innovation and there are considerable unexploited opportunities for collaboration.

4. Further boost the UK's presence and capacity in China to coordinate innovation diplomacy and collaboration for greatest economic and social impact.

The UK needs to invest further to ensure it can sustain the full range of activities required for an effective approach to innovation diplomacy that will unlock long–term economic opportunities for the UK. This will require brokers and intermediaries capable of supporting a full spectrum of relationships. They should recognise when to support individual or supply chain–based collaborative efforts and when to shift attention to transforming the macro policy environment. They also need to ensure better coordination between UK partners in China. As the global innovation system develops, the UK should design more targeted policies to increase its own capacity to absorb, develop and exploit knowledge as well as to generate it. The proposed expert group should work closely with UK representatives on the ground to gather data and identify opportunities and draw lessons from effective practices.

1. CHINA'S ABSORPTIVE STATE

> *"As the global competition in national strength is heating up, we should unswervingly go down the path of innovation with Chinese characteristics."*
>
> **President Xi Jinping, 5 March 2013**[1]

Deep inside China's National University of Defence Technology, on the outskirts of Changsha, a computer is whirring. But this is no ordinary machine. With 3.1 million Intel Core processors, 1.4 petabytes of RAM, and the capacity to perform 33,860 trillion calculations per second, it is the fastest supercomputer on the planet.

In June 2013, China surprised observers by seizing the number one spot in the TOP500, a twice yearly ranking of the world's fastest supercomputers.[2] The Tianhe–2 (Or Milky Way–2) was successfully tested almost two years ahead of schedule. Funded by the Chinese government's 863 High Technology Program, with additional support from Guangdong province, it will eventually be deployed at the National Supercomputer Centre in Guangzhou, where it will be used by researchers from across southern China.

Tianhe–2 is the most impressive result to date of a well–funded and highly–targeted drive by China to move to the fore of supercomputing. It has knocked the US Department of Energy's Titan machine off the number one position, and although the US still dominates the TOP500 (occupying 252 places in the table, including five in the top ten), China with 66 places is catching up fast.

The race is now on to see which country will be first to reach exascale: by producing a supercomputer capable of one quintillion calculations per second. The US, EU, Japan, India and Russia all have ambitions and substantial research programmes directed towards this goal. But most experts expect China to get there first. In his 2011 State of the Union address, President Obama warned that *"This is our generation's Sputnik moment",* as he highlighted supercomputing as one of several fields where the US was in danger of falling behind, and appealed to Congress for more investment in research. Two years on, an exascale strategic plan has only just been submitted to the US Congress, and the prospects for new funding remain uncertain.[3]

In one sense, Tianhe–2 is an achievement that the Americans should be every bit as proud of as the Chinese. It is built using Intel chips, and Intel remains a US company, carrying out a lot of its most valuable R&D in California and other US locations. So while the Chinese media lauded Tianhe–2 as an 'independently–developed' technology,[4] some users of the social media platform Weibo remained sceptical.[5] However, TOP500 editor Jack Dongarra points out that *"Most of the features of (Tianhe–2) were developed in China, and they are only using Intel for the main compute (processor) part…the interconnect, operating system, front–end processors and software are mainly Chinese."*[6] Most analysts agree that it won't be long before China's produces its first fully home–grown supercomputer.

One way of understanding this trajectory is through the concept of 'introduce, digest, absorb and re–innovate.' This concept featured prominently in China's *Medium and Long–term National Plan for Science and Technology Development* (MLP), which was published in 2006 and remains the primary blueprint for innovation policy until 2020.[7] Supercomputing is just one of many priority areas in which foreign technologies are being absorbed, adapted and eventually improved. The same process occurred with several of the technologies that China is most proud of, including its high–speed rail network, nuclear reactors and the Shenzhou spacecraft.

The example of Tianhe–2 suggests that what China's President Xi Jinping terms *"innovation with Chinese characteristics"* will not be a straightforward path from imported to home–grown innovation, but a messier process in which the lines between Chinese and non–Chinese ideas, technologies and capabilities are harder to draw. In this report, we argue that China can now best be characterised as an 'absorptive state', increasingly adept at attracting and profiting from global knowledge and networks alongside its more supportive environment for indigenous research and development.

Taking stock

A great deal of speculation surrounds China's prospects in science and innovation, as with other aspects of China's development and heightened visibility on the global stage. And the same pitfalls – of hype, generalisation and only partial awareness of the domestic political, economic and cultural context – means that discussion of this topic in Europe and the US can sometimes obscure as much as it illuminates.

There is no denying that China is becoming a more significant force in science and innovation. It continues to invest rapidly: in 2012, China's total R&D expenditure exceeded ¥1 trillion RMB ($163 billion USD). In his end of term address, outgoing Premier Wen Jiabao highlighted the 18 per cent year–on–year increase in China's research spending since 2008; a period when the after–effects of the global financial crisis have seen investment flatline or fall in many OECD countries. China is gradually redesigning the policies, institutions and incentives required to stimulate innovation in academia, business and the public sector. And it is drawing heavily on the lessons, experiences and capabilities of other countries in this process, both through international collaborations and by encouraging the return of its high–skilled diaspora.

It is hard to assess an innovation system that is changing so quickly, but this is a good moment to attempt such an exercise. In the past year, China has completed its once in a decade transition to its new leadership, and the Chinese government has embarked on a mid–term evaluation of the 2006 *Medium and Long–term National Plan for Science and Technology Development 2006–2020* (MLP). President Xi has reaffirmed the high–level objectives of that plan but, as a recent commentary in the journal *Science* describes, *"There is growing anxiety among Chinese political and scientific leaders that, despite more money, better–trained talent, and sophisticated equipment, the domestic innovation system is still underperforming."*[8] Further reform of the innovation system is likely to receive attention in the next five–year plan. While research for the 13th Five Year Plan is already underway, the contours of any new policies are not yet clear.

The context for this report

Over the past decade, UK policymakers, universities and businesses have been proactive in supporting research and innovation links with China, with often impressive results. Yet it can still be a challenge for UK stakeholders to navigate the Chinese innovation system and identify the connections that will yield the greatest mutual benefit.

The aim of this report is to analyse the policies, prospects and dilemmas for Chinese innovation over the next decade, in order to inform a more strategic approach to China–UK collaboration. Nesta and its partners – the UK's Department for Business, Innovation and Skills, Foreign and Commonwealth Office Science and Innovation Network, and Research Councils UK – were also keen to update the findings of an earlier 2007 study, published by the think tank Demos.[9] With the Chinese government now reviewing its *Medium and Long–term National Plan for Science and Technology Development* (the publication of which provided the immediate context for the 2007 Demos study) this report focuses on how China's innovation system has changed in the seven years since the MLP was published.

There is no shortage of research, commentary and analysis of different aspects of Chinese innovation, but comprehensive external assessments of its innovation system are more unusual, and are now quite challenging to undertake given the sheer scale of activity. A notable exception was a major OECD review completed in 2007.[10] This report builds on that OECD review, the 2007 Demos report, and a host of Chinese and international studies.

During ten months of research, we analysed over six hundred policy documents, reports, statistical digests and articles (in English and Chinese) to capture the current state of knowledge, scholarship and debate. We commissioned fresh bibliometric data from Thomson Reuters to shed light on the health of UK–China collaborative research. We held three expert workshops: two at Nesta in London with academics, civil servants from BIS and the Foreign Office and representatives of the UK's intellectual property office, and a third at CASTED[11] in Beijing. We also carried out in–depth interviews with experts and stakeholders across government, academia, SMEs and multinational corporations in the UK and China as well as Germany, Australia and the USA.

The many faces of Chinese innovation

In this chapter, we start by outlining five established narratives about Chinese innovation that have influenced debates in China and beyond. None of these offers a complete picture, or tells the full story. But each says something useful about China's progress in innovation, and sheds light on pathways for the future. We then introduce and explain our sixth narrative, from which this report takes its title: that of China as an absorptive state.

- **China as a science and innovation superpower**
  This was the starting point for the 2007 Demos report. China's growing strengths – and likely or inevitable dominance – as a force in global science and innovation is often the way its prospects are framed, usually on the basis of a fairly crude reading of the bibliometric data and assumptions of continued growth.[12] UNESCO's assessment in its 2010 World Science Report is one example: 'China is a hair's breadth away from counting more researchers than either the USA or the European Union, for instance, and now publishes more scientific articles than Japan.'[13] A recent survey of European business leaders by Accenture found that over two–thirds thought China would draw

level or pull ahead of Europe in innovation by 2023.[14] Such predictions are often accompanied by laments for a perceived decline, or existential threat, to the strength of US or European science.[15] Arguably such accounts tell us more about economic or cultural insecurities, or domestic battles for research funding, in other nations than they do about China. There are also plenty of commentators who maintain that the US, in particular, can maintain its strengths despite China's rise.[16] But clearly, if you look purely at the quantity of scientific papers, as a proxy for research strength, then China will outstrip the US by around 2020, and perhaps even sooner.[17] Similar conclusions can be derived by looking at percentage budget increases or the size of the scientific workforce. However, none of this tells you much about the quality of the system, its strengths, weaknesses and multiple trajectories.

- **China as a fast follower**
  This more nuanced position is well articulated by the US analysts Dan Breznitz and Michael Murphree, who argue that China doesn't need to operate at the frontiers of global innovation in order to grow its position in innovation–based sectors and markets.[18] Even as a 'second–generation' innovator, the sheer size and scale of China's domestic market, and its low–cost manufacturing base, mean it is well positioned within increasingly interdependent global networks. Breznitz and Murphree set out to dispel two myths: first, that innovation should only be equated with the creation of entirely new technologies and markets; second, that China's success should be benchmarked against 'an idealized conception of Silicon Valley.'[19] Indeed, they argue, China has been sustaining its long run of economic growth 'by innovating in many stages of production, but not in novel product R&D'. They liken China to Lewis Carroll's Red Queen, who had to run as fast as she could to stay in the same place: 'China shines by keeping its industrial–production and service industries in perfect tandem with the technological frontier. Like the Red Queen, it runs as fast as possible in order to remain at the cusp of the global technological frontier without advancing the frontier itself.'[20] A related point is made by Martin Wolf of the *Financial Times*, who argues that China is yet to produce globally significant 'systems integrator' companies, on which so much of global production and distribution now depends. *"Moreover, such is the lead of the advanced countries' incumbents that it is going to find it extremely hard to do so....The striking feature of (China's) economy remains its dependence on the know how of others."*[21]

- **China as a giant with an Achilles' heel**
  Despite the size of China's economy and its investments in research and innovation, some argue that it has fundamental weaknesses that will prevent it from fulfilling its stated objectives. Will Hutton identifies the problem as the contradictions of an authoritarian state, the lack of transparent institutions and constraints on creativity within China's education system.[22] In a recent article, he concludes: *"Innovation is driven by open interaction...and by the confidence that the law will back any intellectual property rights that you create and protect your profits. None of these preconditions apply in China...China is the classic bubble economy, its innovative capabilities fatally undermined by the one–party state."*[23] A more nuanced version of this argument is made by Daron Acemoglu and James Robinson in their book *Why Nations Fail,* which analyses the governance and institutional underpinnings of economic success. In their discussion of China's growth, Acemoglu and Robinson suggest that it *"is just another form of growth under extractive political institutions...unlikely to translate into sustained economic development."*[24] Others identify shorter–term, but no less fundamental problems, in China's weak enforcement of IP protection, and in its sclerotic enterprise sector, which has little incentive to innovate.

- **China as a techno–nationalist**
  This more hawkish account argues that while there are some encouraging signs of reform and openness within the Chinese innovation system, there is also an ever present undercurrent of techno–nationalism. It identifies threats to the US and Europe from China's 'indigenous innovation' strategy, which it sees as based on forced IP transfer, standards manipulation, discriminatory regulatory and tax policies, and preferential treatment towards state–owned enterprises. A report by the Washington–based think tank, the Information Technology and Innovation Foundation, provides a forceful statement of this position: *"China seeks not merely competitive advantage, but absolute advantage. In other words, China's strategy is to win in virtually all industries, especially advanced technology products and services."*[25] It sees China's 2006 MLP as the start of a 'shift to a 'China Inc.' development model focused on helping Chinese firms, often at the expense of foreign firms. This narrative plays into, and is reinforced by concerns about Chinese state–sponsored hacking and cybercrime, and the theft of industrial secrets, particularly in high–tech sectors. These concerns received prominent international coverage following a 2012 report by the information security firm Mandiant.[26] Advocates of this view argue that R&D collaboration with China is often naïve and the US and Europe instead need to get tougher on Chinese IP infringement, and support China's adherence to international systems of rules–based trade.[27]

- **China as a low–carbon pioneer**
  This more optimistic account suggests that China is playing a longer–term, highly strategic game. Recognising the challenges of climate change, resource depletion, biodiversity and water stress, and the particularly acute pressures these will create for China, it is targeting investment in key areas of low–carbon and sustainable innovation, such as wind, solar and other renewable energy technologies, and frugal resource–efficient manufacturing, that will enable it to lead globally in these sectors as they grow. Solar energy is perhaps the best example of an emerging sector where China has taken a strong global position,[28] although the recent bankruptcy of the main subsidiary of Suntech Power, one of its leading solar panel manufacturers, has somewhat tarnished this.[29] Nonetheless, there is considerable interest and speculation about whether China can direct its innovation efforts towards national and global challenges, for which its more directed model of policy and management is arguably well suited.[30] The big question is whether it uses these strengths to advance collaborative, global solutions – particularly to collective problems such as climate change – or to advance its national self–interest.

China as an 'absorptive state'

As emphasised above, none of these narratives approaches a complete account of the current state or future prospects for science and innovation in China. But their complexity and contradictions are a useful starting point. In this report, we would like to introduce a sixth narrative – that of China as an 'absorptive state' – which captures well the dynamics and tensions now at play within the Chinese system.

The concept of 'absorptive capacity' is a familiar one in innovation debates, and was first introduced by Cohen and Levinthal in 1990 to describe an individual firm's *"ability to recognise the value of new information, assimilate it and apply it to commercial ends."*[31] It refers both to absorption in the conventional sense, and to more specific abilities to exploit and create knowledge. Beyond its application to individual firms, absorptive capacity can also be analysed at the level of regional or national innovation systems, as *"the ability*

necessary for the host country to absorb and adopt new incoming technology from a foreign country."[32] A 2008 Nesta report on global innovation defines it as 'the ability of one place to absorb and adopt knowledge coming from another place.'[33] It goes on to explain: 'Some places are better able to absorb ideas, attract talent and create opportunities than others...These places are magnets for talent, investments and knowledge.'[34]

Why is the notion of China as an absorptive state useful as a way of making sense of its growing strengths in innovation? We suggest three reasons.

First, because absorption is a key feature of China's indigenous innovation policies. The 2006 MLP describes one of its central objectives as strengthening indigenous innovation by *"enhancing original innovation, integrated innovation, and re–innovation based on assimilation and absorption of imported technology."*[35]

Second, it helps to explain what has changed in China's innovation system over recent years. The MLP set out the direction of travel, but only after a sustained period of large–scale targeted investment in basic research, universities and intermediary networks for translation and commercialisation, have the systemic conditions for research and innovation reached a point where the ideas can be effectively absorbed and exploited, with increasingly dense and targeted networks to enable this. This brings with it a sharper focus on those aspects of the system – such as state–owned enterprises – where progress is far slower and more uneven.

Third, it speaks directly to international concerns about how to strike the right balance between competition and collaboration with China through the innovation value chain. In 2006 and 2007, the precise meaning of words like 'absorbing' and 're–innovation', and the mantra of 'indigenous innovation' (zizhu chuangxin), all of which were prominent in the MLP, were hotly debated by analysts in Europe and the US, where some saw them as implying an intention to steal technologies and IP from the west. Seven years on, there is a more measured understanding of the balance between China's indigenous research capabilities (fostered through rapid and large–scale investment) and its relationship to ideas, technologies and firms elsewhere. Many tensions persist, but viewing China's development in terms of enhanced absorptive capacity is a useful lens through which to understand how its innovation system has changed over the past decade, and where it is likely to go next. It builds on the notion of China as a 'fast follower', but goes further to explain how China adds value, creativity and novelty to innovation processes through absorption.

Channels of absorption

In the chapters that follow, we use the notion of China's absorptive state as a framework through which to analyse the strengths, weaknesses, trajectories and uncertainties of its innovation system. There are three main channels through which this process of absorption occurs: an improved structural environment for research and innovation; expanding domestic demand for innovation; and a growing density of international connections.

- **Structural environment**
  Unprecedented growth in investment and research and patent output are features of an increasingly dynamic Chinese system. R&D spending has grown almost 20 per cent a year since the late 1990s, and will outpace that of the US within a decade, and the European Union even sooner. In 2011, Chinese residents overtook residents of the US to become the second largest group of patent applicants worldwide, and are likely to

have overtaken Japanese residents in 2012 to become number one.[36] Yet innovation–driven growth will only take place where the domestic system has the policy framework, the institutions and the capabilities to digest, absorb and embed new technology and knowledge. In this report, we explore two aspects of this shifting structural environment: the national policy framework; and how this translates into China's diverse provincial and regional economies.

In Chapter Two (Indigenous innovation and the 'Chinese dream'), we map significant developments in the policy and investment framework since 2006 and suggest likely directions and priorities for innovation policy under China's new leadership. We look in detail at China's funding inputs, S&T workforce and patent output, and explore the impact of a growing emphasis on quality, efficiency and evaluation.

In Chapter Three (Spotlight on Research), we move beyond the headlines, which show that China is now the second most prolific producer of research papers in the world, to take a deeper look at the data behind this dramatic increase in research output. Based on a detailed new quantitative analysis of the latest data on the output of China's research system, we investigate the strengths and weaknesses of Chinese research, and what it means for the UK.

In Chapter Four (Many Chinas, many innovation systems), we outline the variation in these structural conditions, and in absorptive capacity, throughout the country. Across different Chinese provinces, cities and industrial sectors, there is widespread diversity in implementation and in the pace of change. While research and innovation activity are still highly concentrated on the China's east coast, we highlight how, through a process of 'structured uncertainty', where different actors agree to disagree about the goals and methods of policy, unique models of innovation have developed in Beijing, Shanghai and Guangzhou. We describe how beyond these hotspots, regions tend to follow similar development models, and the concerns that a lack of regional coordination will limit future growth.

- **Demand for innovation**
  While much of the focus of analysis of the Chinese system is on the increasing supply of resources from investment to talent, academics have paid less attention to the equally important demand for innovation within the system. In this report we focus on two elements of demand which are important to understanding the increasing 'absorptiveness' of the Chinese system: the gradual shift towards an enterprise–led innovation system and the strengths of Chinese firms in 're–innovation'; and the mounting pressures for more sustainable economic growth that are driving an emphasis on environmental and social innovation.

  In Chapter Five (The enterprise of innovation), we identify the new cadre of Chinese firms operating at the frontiers of global innovation, and consider how firms in general are responding to government pressure for more R&D–intensive indigenous innovation. In this chapter we explore new models of business innovation that are emerging in China. Previously regarded as a weakness, the quality and speed of China's capacity for incremental re–innovation is now an important competitive asset. We explore how sophisticated manufacturing networks excel in absorbing, adapting, prototyping and market testing new products and technologies at speed and how 'shanzhai' methods of production, which previously referred only to substandard imitation, are of growing international interest as a distinctive way of adding value.

In Chapter Six (Rebalancing growth), we explore how consumers, environmental concerns and civil society are becoming more important as drivers of innovation. More demanding Chinese consumers are pioneering new types of user–driven innovation, a process which will intensify as domestic consumption increases. Environmental and health concerns are prompting a sharper focus on low-carbon and sustainable innovation; and a more proactive and vocal civil society is at the forefront of growing calls for social innovation.

- **International connectedness**
  The third aspect of the absorptive state is perhaps the most obvious: the growing density of China's international connections. Absorption is enabled through increasing flows of people, ideas and technology and the integration of China within global research, innovation and production networks. We focus on two critical aspects of this connectedness: firstly the evolving patterns of China's international research collaboration and how we should interpret the latest data to judge the UK's relative position in these, and secondly the thorny issue of risk and national interest in international innovation collaboration.

  In Chapter Seven (Innovation diplomacy and collaboration), we use the latest data to review China's global research partnerships and the current landscape for China–UK collaboration. We reveal that the UK has recently moved ahead of Japan to become the second most popular partner for Chinese researchers after the USA. For any country seeking to collaborate with China, ensuring a diversity of connections beyond research is crucial. In this chapter we benchmark the national strategies of several key countries towards collaboration with China in terms of strategic frameworks, trade and business links, student flows and influence on Chinese policy. We find that each country's strengths and modes of engagement are unique and the transfer of 'best practices' in collaboration is rarely straightforward.

  In Chapter Eight, (The real risk equation), we discuss the 'dark side' of absorption by looking at international flows of ideas and technology resulting from IP theft, forced technology transfer and cybercrime. Given that this is now a significant feature of the more hawkish perspectives on Chinese innovation, we explore how an increasingly absorptive Chinese system brings both risks and opportunities for businesses, universities and others seeking to work with and in China. We discuss how these risks need to be managed with care, and the need for smarter communication of the 'risk equation' from government to those who are thinking about engaging in innovation partnerships in China, but argue that they should not be over–emphasised such that they eclipse a far greater risk – that of failing to participate fully and benefit from the next phase of China's growth.

  In Chapter Nine (China–UK: Partners in the global innovation race), we conclude with a series of headline recommendations for ways in which UK–China collaboration can be strengthened: for example, through development of a stronger, multi–level innovation dialogue and targeted investment in collaborative R&D linked to Chinese and UK priorities (for example, the UK's 'eight great technologies').

  Innovation is caught up in a bigger unfolding debate about the pace, scale and direction of China's economic and political reforms. Much still depends upon the playing out of a set of tensions: between the planned economy and the market; national and global priorities; the hardware of research infrastructure and the software of culture and ethics; the skills and creativity of home–grown talent, and the entrepreneurialism and networks of returnees. In the decades to come, China is likely to change innovation just as much as innovation changes China.

2: INDIGENOUS INNOVATION AND THE 'CHINESE DREAM'

> *"The Chinese dream is the great renaissance of the Chinese nation."*
> **Xi Jinping, November 2012**

On 29 November 2012, two weeks after he was confirmed as the head of the new Politburo Standing Committee, Xi Jinping led his committee colleagues on a tightly–choreographed day trip to the National Museum in Tiananmen Square. Upon arrival, China's incoming leaders viewed an exhibition called Road to Rejuvenation, which depicts China's journey from the hardships and humiliations of the 19th century to a restored greatness in the 21st century. In his informal remarks that day to a group of reporters and museum workers, Xi spoke of the 'Chinese dream', an idea that he returned to five months later in his inauguration speech as president.

Given that Chinese leaders are not known for spontaneously introducing new political concepts, there is speculation as to why Xi has given the 'Chinese dream' such prominence. Some have suggested that he borrowed it from the columnist Tom Friedman; others that it is his restatement of longstanding notions of revival and renaissance.[37] But the phrase has quickly taken off, with government campaigns launched to promote it in schools and the civil service, a dedicated website affiliated to the *People's Daily,* and a TV talent show to find *The Voice of the Chinese Dream.* Academics are even being asked to come up with Chinese dream research proposals.[38]

The dream is inspired by the so–called 'two 100s' that provide the context for China's highest level goals: to become a 'moderately well–off society' by 2021, the 100th anniversary of the birth of the Chinese Communist Party; and to become a 'rich, strong, democratic, civilised and harmonious socialist modern country' by 2049, the 100th anniversary of the founding of the People's Republic of China.[39] Science and innovation are important elements of this journey of national renaissance, as reflected in China's ambitions to become an 'innovation oriented nation' by 2020 and a 'world science and technology power' by around 2050,[40] which are set out in the MLP.

Yet a 'dream' seems the opposite of a plan – certainly the kind of long–range planning that defines the Chinese system to many Western observers. Dreams are often messy, uncoordinated and full of contradictions. Look beneath the surface of the Chinese innovation system though, and one finds more of these characteristics than one might expect.

In this chapter we look first at some of these contradictions, which are inherent in the Chinese approach. We then offer a snapshot of structural factors within the Chinese system and indicate where they are heading, based on the latest available data.

The contradictions of an absorptive state

As the concept of indigenous innovation continues to develop, it's clear that absorbing, attracting, improving and owning knowledge from elsewhere is a core strand of policy. According to official definitions of 'indigenous innovation', it is comprised of three concepts as set out in Table 1:

Table 1: **Three concepts of indigenous innovation**

Chinese	Pinyin	Official translation
原始创新	Yuanshi Chuangxin	Original innovation
集成创新	Jicheng Chuangxin	Integrated innovation
引进消化吸收再创新	Yinjin Xiaohua Xishou Zai Chuangxin	Re-innovation based on assimilation and absorption of imported technology (Literal translation: Introduce-digest-absorb re-innovation)

Source: Medium and Long-term National Plan for Science and Technology Development 2006-2020 (MLP)[41]

The economist Mariana Mazzucato has written persuasively of the need for governments to recognise, value and exercise their agency as architects of an 'entrepreneurial state', able to direct policy and investment towards priority technologies and shape emerging markets.[42] Certain aspects of an 'entrepreneurial state' are already visible in China (for example in its strategic investment in renewable energy technologies) but there is still some distance to go before it reaches the kind of dynamic public-private innovation system that Mazzucato describes in places like Silicon Valley. For now, running through all of China's national plans is an acute contradiction: *"China's national innovation system struggles to balance its need to utilize foreign sources of technology with a desire to nurture home-grown innovation."*[43]

There is a considerable literature on the tensions between foreign direct investment (FDI) and indigenous innovation in China.[44] On the one hand, the MLP says that China should: *"Assimilate and absorb a series of advanced technologies, master a number of critical technologies concerning the nation's strategic interests, and develop a range of major equipment and key products that possess proprietary intellectual property rights."*[45] It also says that China should reduce its dependence on foreign technology to 30 per cent by 2020.[46] The 12th Five Year Plan (FYP), launched in 2011, dropped this metric,[47] instead stating that China *"will actively expand imports of foreign technology"*[48] and *"bring in senior talent and advanced technology from overseas and encourage foreign enterprises to set up R&D centres in China in order for China to learn advanced international management concepts and systems."*[49] This perhaps reflects a growing recognition by Chinese policymakers of quite how dependent the drive for indigenous innovation is on inflows of foreign technologies and ideas. Table 2 identifies progress against targets in the MLP.

Table 2: **Select MLP targets and progress**[50]

	Target for 2020 set in 2006	Achievement as of 2012
R&D expenditure as a share of GDP	2.5%	1.98%[51]
The contribution of progress in science and technology to economic growth	60%	51%[52]
International ranking for patents granted to Chinese nationals	Top 5	2[53]
International ranking for number of citations of scientific papers	Top 5	5[54]
Dependence on foreign technology	30%	Metric dropped

China's reliance on foreign technology is illustrated by its high-tech exports, of which 79.9 per cent were so called processing exports in 2010, where foreign technology is imported, assembled in China and then exported.[55]

To drive China's industries up the value chain, the 12th FYP identified 'seven strategic emerging industries' to drive China's industries up the value chain, the 12th FYP identified 'seven strategic emerging industries' which are receiving preferential investment and policy support.[56] The plan states that R&D and indigenous innovation must be a 'core feature' of these new industries,[57] which are intended to grow at 20 per cent per year, to account for 8 per cent of GDP in 2015, and around 15 per cent in 2020,[58] up from 3 per cent in 2005.[59]

The seven strategic industries are:

- Energy conservation and environmental protection.
- Next generation IT.
- Biotechnology.
- High–end equipment manufacturing.
- New energy.
- New materials.
- New energy vehicles.[60]

Table 3: **Economic overview**

	China	Brazil	India	UK	US	Germany	Australia
Population (World Bank,[61] 2012)	1,350,695,000	198,656,019	1,236,686,732	63,227,526	313,914,040	81,889,839	22,683,600
GDP (Current trillion US$, World Bank, 2012)	8.227	2.252	1.841	2.435	15.684	3.399	1.520
GNI per capita (PPP, current international US$, World Bank, 2012)	9,210	11,720	3,840	36,880	50,610	41,890	43,300
GDP growth (Annual %, World Bank, 2012)	7.8	0.9	3.2	0.3	2.2	0.7	3.4
Literacy rate (Adult total, %, World Bank)	94 (2010)	90 (2009)	63 (2006)	99	99	99	99
Public spending on education (% of GDP, World Bank, 2010)	4 (2012)[62]	5.8	3.3	5.6 (2009)	5.6	5.1 (2009)	5.1 (2009)

Coordination challenges

As R&D activities at mission–oriented agencies like agriculture and health increase, and as the Ministry of Finance and the National Development and Reform Commission take responsibility for areas of reform alongside the Ministry of Science and Technology, coordination issues are brought into sharp relief. While multiple sources of funding can be helpful, experts argue that a lack of overall coordination is creating serious inefficiencies in the system, such as an inability to deal with crises (e.g. the SARS outbreak in 2003), and the problem of well–established researchers getting identical projects funded by different agencies.[63] These problems are compounded by deficiencies in national quality controls and evaluation and serious issues with misconduct and plagiarism in the research system.[64]

Table 4: **Benchmarking China's S&T performance**

	China	Brazil	India	UK	US	Germany	Australia
GERD (% of GDP, OECD,[65] 2011)	1.84	1.16[66] (2010)	0.76[67] (2007)	1.76	2.77	2.88	2.2 (2010)
Patent grants (to residents at domestic patent office, WIPO,[68] 2011)	112,347	380	776	4,938	108,626	21,789	1,267
National share of world publications (Thomson Reuters, 2011)[69]	12.73	2.75	3.67	7.6	28	7.47	3.4
Researchers in R&D (per million population, World Bank)	863 (2009)	704 (2010)	136 (2005)	3794 (2010)	4,673 (2007)	3979 (2010)	4294 (2008)

The next wave of reforms

While the MLP and earlier plans had a strong focus on technological achievements, recent plans emphasise the economic and social benefits of innovation.[70] Notably, the 12th FYP called for innovation for public benefit and strengthening regional growth.[71] There is also a sharper focus on value for money and return on the enormous investment that government is making in the research and innovation system.

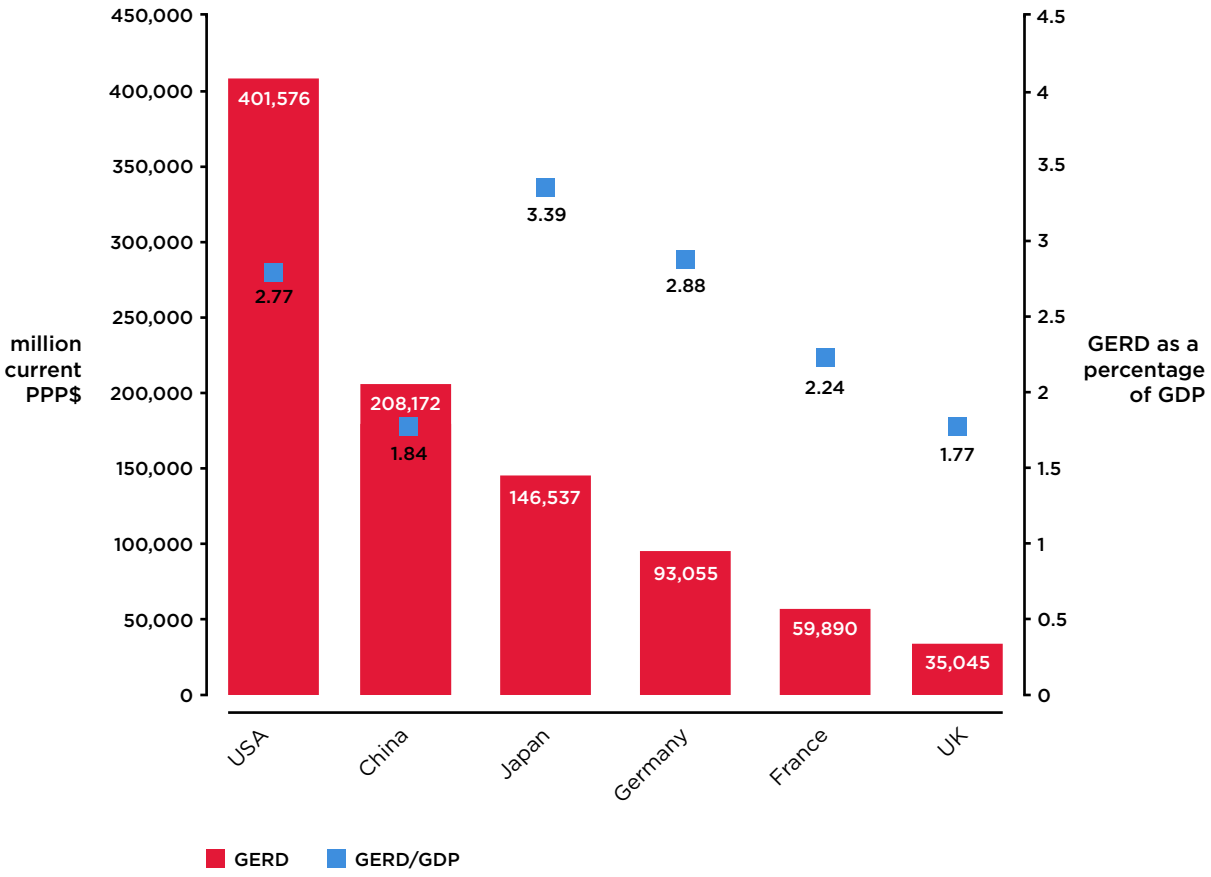
In July 2012, the Chinese Academy of Sciences hosted a conference to review progress since the launch of the MLP. A subsequent document titled: *Opinions on Deepening the Reform of the Scientific and Technological System and Speeding up the Building of a National Innovation System* identified priorities for further reform, including clearer definition of the mission of national R&D programmes; separation of entities for funding, research and performance evaluation; improving the sophistication of evaluation processes; and making reward systems more open and transparent.[72] In addition, a formal mid–term review of the MLP is now underway and is expected to be completed in the second half of 2014.

In this context, we will look in more detail at three dynamic areas of China's national innovation system: funding; human capital inputs and patenting outputs followed in the next chapter by an in depth look at China's research outputs.

Funding research and innovation

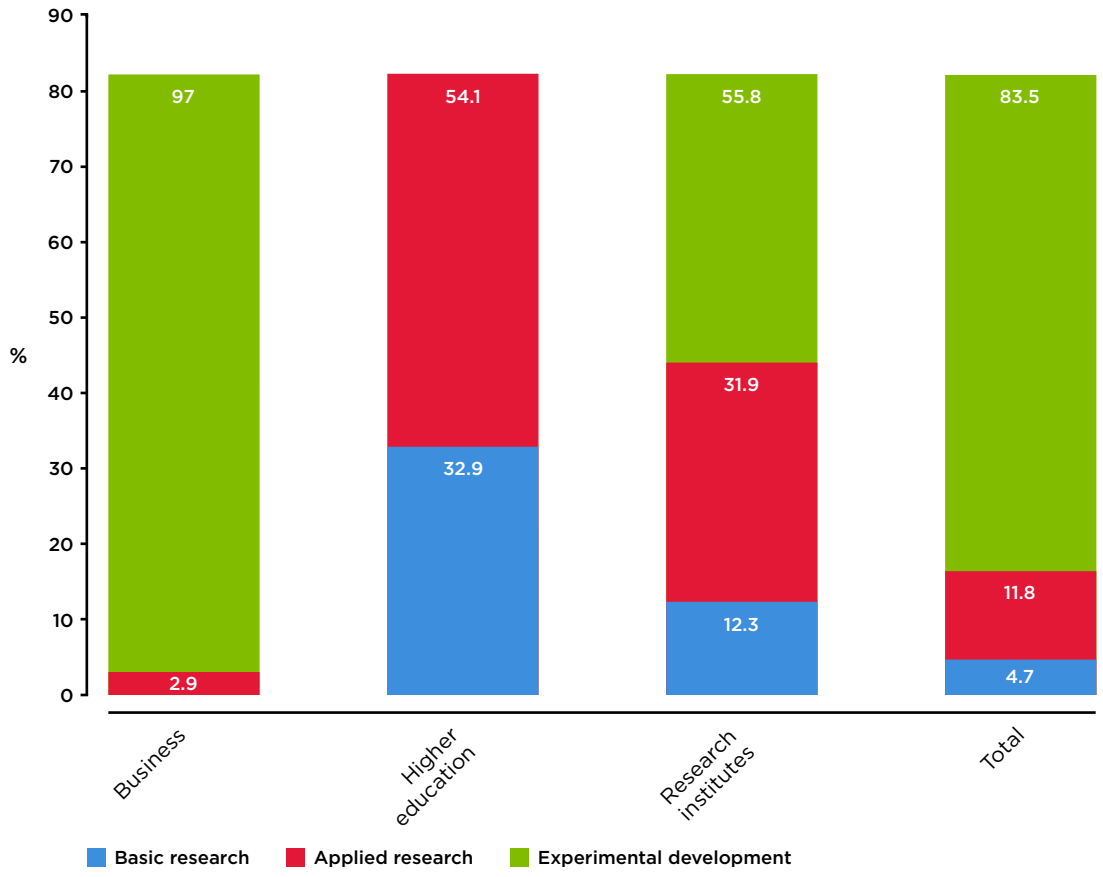
In 2012, China's total expenditure on R&D exceeded one trillion RMB, or $163 billion, an 18 per cent increase on the previous year. Gross expenditure on R&D (GERD) as a share of China's GDP rose from 0.5 per cent in the mid–1990s to 1.84 per cent in 2011, and 1.97 per cent in 2012,[73] a huge absolute spending rise in an economy that grew by a factor of ten over the same period. Figure 1 shows how this stacks up against leading spenders. Much of the growth has been driven by the business enterprise sector (BERD), the contribution of which increased from 60 per cent of GERD in 2000 to over 75 per cent in 2011.[74]

Figure 1: **Gross domestic expenditure on R&D by top six countries, 2011**[75]



Applied research and development account for the lion's share of China's spend.[76] Even recent statistics show basic research accounting for less than 5 per cent of total R&D expenditure,[77] which some argue inhibits the potential for breakthrough discoveries.[78] The National Natural Science Foundation (NSFC) mainly supports basic science research, through competitive and peer reviewed applications.[79] Its expenditure on research of 14.6 billion RMB (US$2.38 billion) in 2011 accounted for around 7.7 per cent of R&D expenditure by the Chinese government.[80]

Figure 2: **Breakdown of R&D expenditure by type of activity, 2011**[81]



Government funding of science and technology programs is split across three main agencies: the Chinese Academy of Sciences (CAS), the National Natural Science Federation of China (NSFC) and the Ministry of Science and Technology (MoST).[82] The precise division of financing for applied R&D is more difficult to determine. China's financial system is dominated by state–owned banks which provide loans at preferential rates to state–owned enterprises (SOEs), with smaller companies suffering severe credit shortages for business R&D.[83] Chapter Five of this report reviews business R&D financing initiatives in more detail.

Measuring China's 'hidden innovation'

While measuring R&D expenditure gives us an important indication of progress in innovation, it provides only a partial picture of innovative performance. In the UK, Nesta's work has been influential in bringing to policymakers' attention the fact that, in addition to investment in research and development, economic success depends on the downstream co–investments needed to commercialise and profit from new ideas: factors such as design, organisational improvements, training, software development and brand equity.[84] These important elements are hidden from traditional statistical measures. For instance, the latest research for the UK shows that investment in R&D represents only 13 per cent of all investments in intangible assets.[85]

It is clear that investment in intangibles is more abundant in developed economies and there has been little published work to date that aims to measure intangible investments within the Chinese economy. Recent work by Hulten and Hao is an exception, and appears to indicate that, alongside the huge tangible investments China has made, intangible capital is becoming an important source of growth for firms, albeit in inefficient ways.[86]

Intangible investments in innovation, across sectors from manufacturing to services and creative industries, will be essential to China's future absorptive capacity and innovative performance. This is one measure that the world should watch with interest.

China's scientific and engineering workforce

An educated and skilled workforce is a crucial aspect of any national innovation system. In 2010, China launched its first comprehensive plan on human resources, the National Medium and Long–term Talent Development Plan (2010–2020),[87] which sets a target of 180 million 'highly skilled workers' by 2020, up from 114 million in 2010.[88] This huge expansion will flow from sustained investments in education, which increased at an average of 21.58 per cent per year between 2007 and 2012.[89]

In 1998, 830,000 students graduated with a higher education qualification in China. By 2012, graduate numbers hit 6.2 million,[90] and by 2020, they are predicted to reach 10.5 million. This would account for almost a third of the world's total, and more than the USA and EU combined.[91] In 2011, 41.61 per cent of Chinese students graduated with a degree in science or engineering (compared to 23 per cent in the UK and 15 per cent in the US in 2010).[92] These graduates contribute to China's vast R&D workforce which in 2011 accounted for 25 per cent of the world's total.[93]

But the quality of China's graduates has not kept up with these huge leaps in quantity. A report by the consultancy McKinsey found that only 10 per cent of Chinese engineering graduates meet global employability standards.[94] Many argue that the root of China's low–quality graduates is an education system that does not encourage creativity.[95] *China 2030,* a report coauthored by the World Bank and the Development Research Centre of China's State Council, says: *"Perhaps the greatest challenge is how to encourage creativity and initiative, attributes that are urgently needed as the country strives for technological maturity."*[96]

China's S&T workforce is also uniquely afflicted by the disruption that the Cultural Revolution caused to the education system between 1966 and 1976. Denis Simon and Cong Cao argue that this has led to a missing generation of qualified S&T personnel in their 50s to 60s. As a result, the leaders of China's S&T workforce tend to be younger and less experienced than their counterparts in the west.[97]

Attracting talent back to China

Chinese students who study abroad and return to China play a key role in China's innovation system. Yet as the number of overseas students continues to increase rapidly and the quality of China's own universities steadily improves, a foreign degree no longer carries the premium it once used to. Graduates who come back to China with work experience on the other hand are more valuable than ever. These returnees act as an important conduit for the skills, contacts, management abilities and technologies that China's drive to become a more innovative nation requires.

In 2011, a total of 339,000 Chinese students went abroad to study,[98] the largest national cohort of overseas students globally. Simon and Cao note that data on returnee students is notoriously difficult to collect,[99] but the best estimates from the Ministry of Education show that over 810,000 Chinese students have returned to live and work in China since 1978.[100]

The Chinese research system has strong ties to the west. Figures from Yu Wei, deputy director of the office of scientific research at Peking University show that 47 per cent of the lead scientists on MoST's major research programmes between 2006 and 2011 received their PhDs from a foreign institution.[101] Returnees also play an important role in the administration of China's S&T system: both China's Minister of Science and Technology, Wan Gang, and Yang Wei, the head of the National Natural Science Foundation of China (NSFC) received their PhDs abroad, and the president of the Chinese Academy of Sciences, Bai Chunli, also did post–doctoral training abroad.

However, with the quality of China's top universities steadily increasing, a degree from a foreign university is no longer a guarantee of a good job. Where returnees are still highly valued is in the experience they have gained from working or carrying out research abroad. This will be an important trend to watch for countries like the UK, the US and Australia which currently receive large cohorts of international students from China.

Research by Wang and Zweig shows how returnees who have worked abroad have played 'a leading role in many aspects of China's 'going out' strategy.'[102] Crucial to this are the contacts that they bring with them, their access to foreign investors and their knowledge of foreign research cultures.[103] As Chinese companies seek to expand their global operations, the value of such experience will continue to grow.

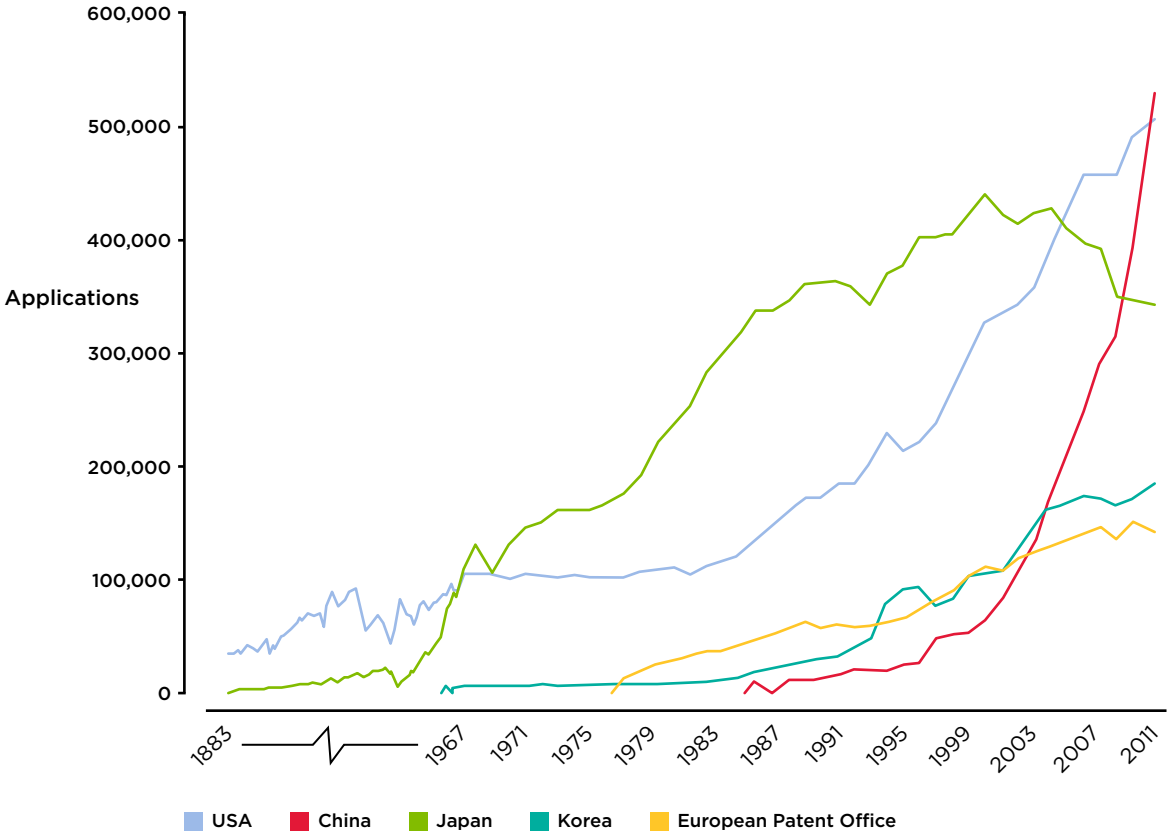
Management skills are another area where returnees are highly valued. Multinationals in China face a chronic shortage of management skills[104] and whereas they previously filled this gap with expatriate managers, they now increasingly look to returnees.[105] One recent study confirmed the value a returnee can bring to a company, finding that companies which have board members with overseas management experience had greater profitability and productivity.[106]

Recognising the benefits that returnees bring to the Chinese economy, the government has put a lot of effort into attracting Chinese graduates back to China through targeted schemes. The Thousand Talents Program (2008) and the Thousand Youth Talents Program (2011) had sponsored 2,263 academics by the end of 2012.[107] However, these schemes have also been criticised both for failing to attract the best academics back to China and failing to persuade them to relocate in China permanently.[108] On the business side, several provinces across China have built 'Pioneer Parks' to attract returnee entrepreneurs with generous subsidies.

China's patenting surge

In 2011, China's patent office, SIPO, overtook that of the USA to receive more patent applications than any other country in the world.[109] Between 2009 and 2011, patent filings worldwide increased by 293,900, with the Chinese patent office SIPO accounting for 72 per cent of this growth.[110] This is a remarkable rise from a country whose patent law only came into effect in 1985. Growth has been driven overwhelmingly by domestic applicants, who filed 82 per cent of patent applications in 2012.[111] While this patent explosion has been broadly welcomed by Chinese policymakers, others have queried the extent to which it represents genuine innovation.[112]

Figure 3: **Trend in patent applications for the top five offices** (reproduced from WIPO 2012)[113]



China's patent system grants three types of patents: invention patents, utility models and industrial designs.[114] Invention patents, which are most similar to patents in the UK, accounted for just over a quarter of China's 1.9 million domestic patent applications in 2012. Utility models, which are granted for incremental technological improvements, and industrial designs, which are granted for the external appearance of a product do not undergo a substantive examination.[115] Richard Suttmeier, a US analyst of China's innovation policies, expresses concern about China's explosion in utility patents: *"It is not entirely clear whether this phenomenon serves the development of genuine innovative capacity in China."*[116] In a report for the US Chamber of Commerce, patent lawyer Thomas Moga argues that the utility model system has created *"patent weapons that are disruptive to normal business growth."*[117] This disruption occurs when so called non–practicing entities, or 'patent trolls' buy up cheap patents solely for use in malicious patent litigation.

Others suggest that the utility model system suits China's current stage of development. Because they are typically granted in under a year, they are 'most appropriate for products with lower levels of inventiveness and/or short lifecycles (which require they enter the market quickly).'[118]

Table 5: **Chinese patent applications by type, 2012**

	Total	Invention	Utility Model	Industrial Design
Domestic	1,912,151	535,313	734,437	642,401
Non–resident	138,498	117,464	5,853	15,181
Total	**2,050,649**	**652,777**	**740,290**	**657,582**

Source: SIPO, 2012.[119]

Government policy has been one of the primary drivers of this boom in patents.[120] China's National Patent Development Strategy (2011–2020) set a target of two million annual patent applications by 2015 (up from around 1.2 million in 2010), a goal it reached three years early in 2012.[121] Local governments also set their own targets: the EU Chamber of Commerce in China found 150 patent targets in policy documents at the provincial and municipal level.[122]

The National Patent Development Strategy also sets a target to double the number of patent applications filed by Chinese applicants abroad.[123] Although less dramatic than domestic patenting, China's international patent applications are also increasing rapidly. For example, Patent Cooperation Treaty (PCT) applications rose from 5,455 in 2007 to 18,614 in 2012.[124]

To support these targets, central and local governments offer a range of subsidies and incentives. Research by Li Xibao at Tsinghua University shows that subsidies were the primary driver of patent growth between 2000 and 2007.[125] In many cases, local governments directly pay patent application and examination fees.[126] Incentives include a reduced corporate tax rate of 15 per cent (down from 25 per cent), to firms that qualify as High and New Technology Enterprises (HNTE), with number of patents filed one of the core qualification criteria.[127] Patent application targets are also an element of performance measurement for managers of central SOEs.[128]

While China is the world's number one in terms of number of domestic patent applications, in 2011 it had fewer than 700,000 patents in force, compared to over 2.1 million in the US.[129] Data from SIPO shows that the average lifespan of an invention patent filed by a domestic applicant was 6.9 years in 2011, compared to 10.3 years for foreign applicants and over half had a lifespan of less than five years, compared to 15.2 per cent for foreign patents.[130] A 2005 survey of academics in the nanotechnology sector in China found that almost half had no interest in licencing or utilising their patents, which they had filed purely for career advancement.[131]

Sectorial strengths

A small number of studies have sought to use the pattern of China's patent applications to evaluate and predict shifting sectorial strengths in innovation. However, the evidence is inconclusive. A Thomson Reuters analysis of patents published between 2005 and 2010 found the main growth areas were electrical machinery apparatus and energy, digital communication and computer technology. The report predicts continued growth in these areas, alongside the seven strategic emerging industries identified in the 12th FYP.[132] A different Thomson Reuters report compared the fields in which China is patenting to the global average for each field, and found that 'China shows no particular dominance in any one technology field, indicating that innovation is broadly balanced across the spectrum.'[133]

Recent analysis of US Patent Office data reminds us that patenting data presents a skewed picture of sectorial strength. It found that 'a tiny number of Chinese companies, concentrated in the ICT equipment industry, accounts for the largest share of the dramatic increase in USPTO patents held by Chinese residents.'[134]

Patented futures

The significant proportion of low–quality patents has been recognised by the Chinese government, which is now setting out to change incentive structures. In 2013, the government issued a fresh implementation plan for its National Intellectual Property Strategy, aimed at encouraging IP creators 'to transfer their focus from quantity to quality.'[135] This follows a 2012 statement from the Ministry of Science and Technology which indicated that career advancement of government staff would be decoupled from the number of patents filed and connected instead to a broader index of research and innovation performance.[136] National news outlets have reported Tian Lipu, the head of China's State Intellectual Property Office, as saying that incentives should be overhauled to focus on international and invention patents, rather than utility models and industrial designs.[137]

Though there are many problems associated with the huge investments China has made in driving the output of its patent system, Professor Mu Rongping of CAS IPM argues that it shouldn't be viewed as a failure. Indeed, he believes *"resources spent on the patent system have been like a tuition fee, teaching scientists how to file patents and why they are important. This has been a learning process, but in the next two years the government is likely to stop its support and let people file patents on their own."*[138]

Where next for China's indigenous innovation policies?

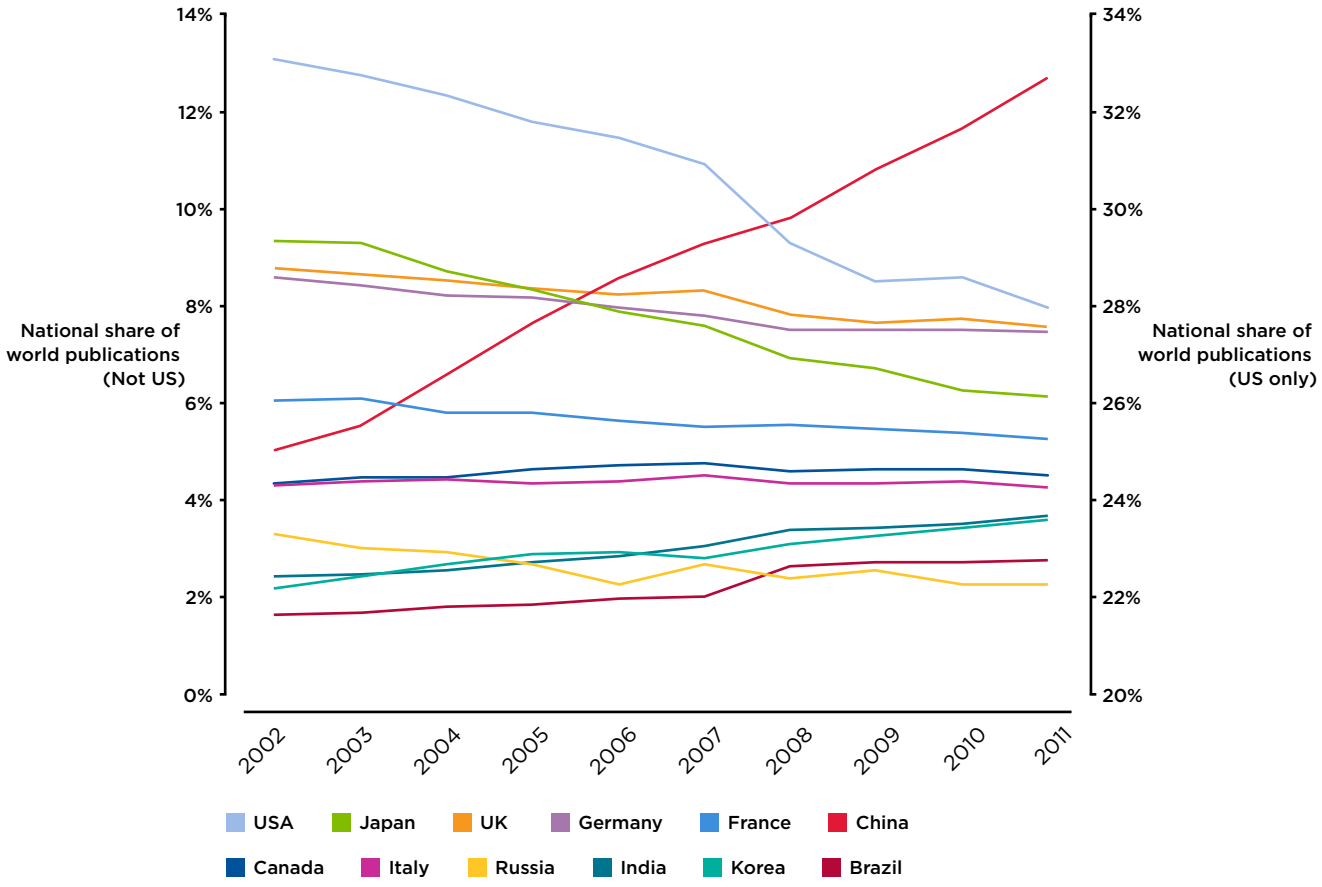
A policy focus since the early 1990s on investment and growth has propelled China into the top ranks of global R&D investment, and publication and patenting output. China looks on track to realise its dream of becoming an 'innovation oriented nation' by 2020, an achievement which is due in no small part to its deep connections to global sources of technology and expertise and its growing ability to absorb and exploit them. But a deeper look at the available data shows that the process of becoming a more innovative nation has been highly inefficient. Government policies are now being complemented by a growing focus on efficiency, quality, coordination and evaluation.

In the next chapter we take a deeper look at the data behind China's dramatic increase in research output and investigate the strengths and weaknesses of Chinese research.

3: SPOTLIGHT ON RESEARCH

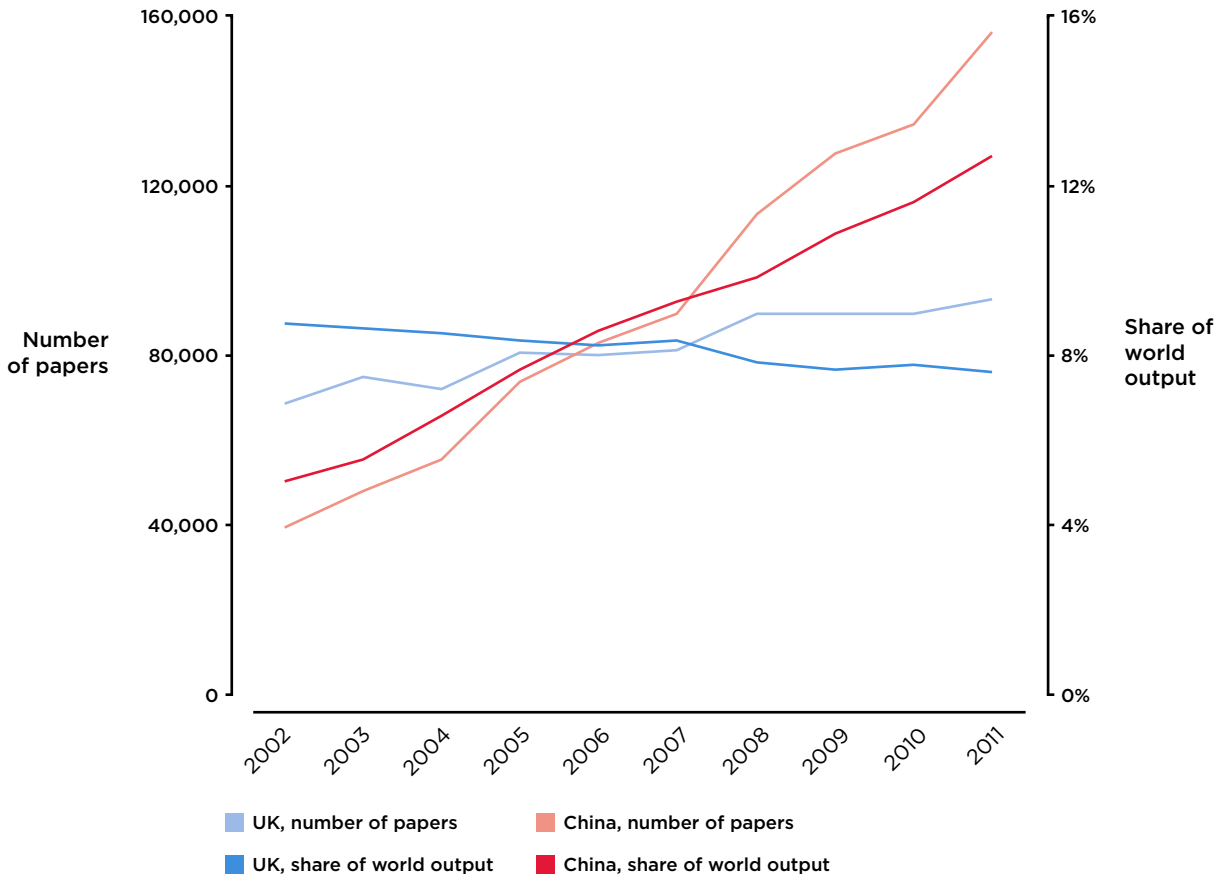
The headline statistics on the growth of the Chinese research base are staggering.[139] Over the last 30 years, research output has grown from around 2,000 to over 150,000 journal articles and reviews per year.[140] This represents the most rapid expansion of a national research system ever seen. For this report we undertook detailed new quantitative analysis of the latest data on the output of China's research system. The unprecedented growth and dynamism we found at a subject and institutional level means that, unlike established research economies such as the USA and UK, which are relatively stable from year to year, the strengths, weaknesses and opportunities of China's research base are very difficult to assess and predict. For this reason we reach beyond the averages to shine a spotlight on the Chinese research trajectory. Further detail is available in the online bibliometric annex to this report.

Figure 4. **National share of world publications indexed on Thomson Reuters' *Web of Science*, 2002–2011.** Data shown for G7 and BRICK nations (Brazil, Russia,India, China, South Korea), which collectively authored 8 million of 10.9 million papers indexed globally in the decade[141]



Relative to other countries, China increased its share of world output from about 5 per cent in 2002 to around 13 per cent in 2011 (Figure 4). During the same period, the US share fell from 33 per cent to 28 per cent and although UK output rose in absolute terms its global share fell from 9 per cent to 7.5 per cent (Figure 5). Unlike G7 countries, where international collaboration accounts for the lion's share of growth over the last 25 years, the growth of China's research output is driven primarily by increased domestic activity.

Figure 5. **Absolute and relative numbers of publications indexed on Thomson Reuters' *Web of Science* for the UK and China, 2002–2011**[142]



In 2013 MoST released the *Guidelines for the 2014 National S&T fund on publishing of S&T works.*[143] As well as a focus on the seven strategic emerging industries and basic research, the strategy also showed the government's ambition for Chinese research to make more of an impact on the world stage, with outstanding academic papers written in English as one of the key areas it would fund.

A high–level overview of the quality and quantity of research papers is useful but hides important details, even when viewed by major scientific field. Beneath these headline numbers, we need to consider the spread of growth in research activity across subject areas, and how this compares with the portfolio of a country like the UK.

It is important to understand the breakdown of activity within the Chinese system. The balance of China's research portfolio is strongly tilted towards physical sciences and engineering. This contrasts to that of the UK, which is balanced towards life sciences. Rapid

growth is pervasive throughout the system. It is notable in large fields such as engineering, as well as fields that are newer to Chinese researchers, such as molecular biology. There are also a few fields showing exceptional growth in recent years – for instance, biomaterials grew 15–fold in the last decade.

The fields that have grown most rapidly are those that were a formerly a relatively small part of total output. Other large research fields, for example Physics, Materials Science and Chemistry have grown more slowly than the national average. China's research has tended to be strongest in areas associated with manufacturing industries: for example, it currently has a 20 per cent world share of chemistry publications, up from 10 per cent in 2002 (this is an area that has become a smaller part of the UK portfolio over the last 30 years). By contrast, growth in the biomedical sciences is accelerating much more rapidly. For example, China's global share of Molecular Biology and Genetics was around 1 per cent in 2000 and is now over 10 per cent, which is an increase from 1.8 per cent to 2.7 per cent of China's total output. See the online report annex for far greater detail.

The finer grained journal categories in Thomson Reuters' data are the 256 categories used in the *Web of Science.* Some 80 of these have a growth rate that is greater than the China research base average (around four–fold) but in many cases that difference is not very great (>4 but <5). Table 6 shows outlier growth in output.

Table 6. **Select outlier examples of high growth rates for China's research analysed at the level of Thomson Reuters' *Web of Science* journal categories**[144]

	Growth factor in decade	Recent annual total
Food Science and Technology	8–fold	1,500 papers
Medicinal Chemistry	12–fold	1,000 papers
Integrative and Complementary Medicine	15–fold	550 papers
Orthopaedics	Over 7–fold	425 papers
Mathematical and Computational Biology	8–fold	300 papers
Materials Science – Biomaterials	15–fold	160 papers
Nanoscience and Nanotechnology (core journals)	7–fold	115 papers
Physical Geography	11–fold	110 papers

Other categories in the molecular/biomedical area that grew faster than the national average, if less spectacularly than those in Table 5, and now have a large annual volume in excess of 1,000 papers per year are Pharmacology and Pharmacy (2,600 annual papers), Biotechnology and Applied Microbiology (2,500), Oncology (2,130), Neurosciences (1,900), and Research and Experimental Medicine (1,570). On the other hand Biochemistry and Molecular Biology (2,500 papers) grew more slowly than the average.

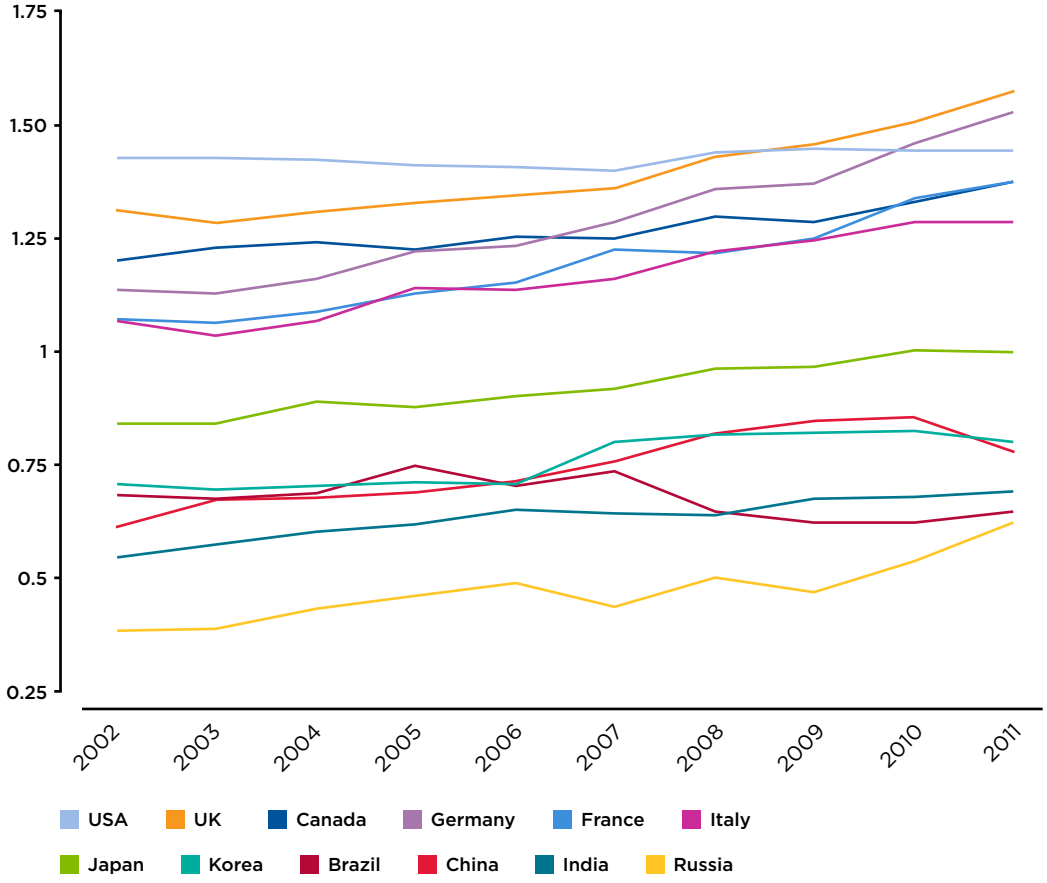
Telecommunications (1,580 papers per year), Water Resources (1,080), Energy and Fuels (980), Electrochemistry (870), and Materials Science – Coatings and Films (820) were among the categories on the technology side that grew faster than average. Although growing more slowly than the average, Optics (4,685) and Applied Physics (in excess of 6,000) are large research fields for China and grew more than three–fold.

Some ESI fields showed a very mixed pattern at the finer *Web of Science* level. For example, Materials Science – Composites (270 papers per year) contracted, unlike other areas of Materials. Similarly, Computer Science – Theory and Methods (580 papers per year) contracted rapidly and Computer Science – Artificial Intelligence (over 1,000) hardly grew at all.

This evidence highlights the need for analysts to be cautious in interpretation of general bibliometric indicators of China's research performance without more detailed examination. Some large fields have grown by an absolutely large amount, far beyond the capacity of most G7 nations; others have grown more slowly than the China average. Some fields have niche peaks and troughs of growth only evident under close scrutiny.

Another important question is whether this growth in output has come at the expense of quality? Judging the quality of research is difficult. The value of research publications is reflected in their subsequent impacts, which may be academic, economic and social. As social and economic factors are hard to quantify, we use citations – the number of times a work is subsequently referenced by later publications as an indicator of academic impact.[145]

Figure 6. **Normalised citation impact (world average = 1.0) of research papers published by G7 and emerging countries, 2002–2011**[146]



While China's normalised citation impact is still below world average in most areas, the data in Table 7 shows that it is close to that benchmark in a number of fields, including engineering and mathematics, and consistently above average in agriculture. Overall citation impact may in fact be improving more rapidly than indicated in previous analyses as a result of China's unique growth rate. (See online bibliometric annex for further analysis.)

There is no general relationship between the size or growth rate of any field and its average normalised citation impact. Table 7 shows shifts in the impact of key fields in the last five years.

Table 7. **Normalised citation impact by ESI field for China papers from 2003–2011**[147]

The table is ranked by average impact for the last five years (2007–2011). 'Gain' is calculated as the ratio between the average impact for the last three years and the first three years.

	Publications '03–'12		Normalised citation impact		
	Count	Growth	03–'11	07–'11	Gain '03–05 vs '09–'11
Microbiology	10,569	7.96	0.73	0.72	0.77
Neuroscience and behaviour	15,903	6.46	0.75	0.75	0.94
Immunology	7,404	9.37	0.75	0.76	1.03
Space science	7,252	2.53	0.76	0.79	1.37
Biology and biochemistry	42,473	4.61	0.79	0.81	1.23
Pharmacology and toxicology	23,408	6.49	0.81	0.82	1.03
Molecular biology and genetics	20,648	8.48	0.82	0.83	0.92
Clinical medicine	93,303	6.17	0.84	0.84	0.95
Plant and animal science	34,967	5.07	0.82	0.84	1.07
Materials science	114,482	3.51	0.84	0.86	1.16
Chemistry	227,049	2.90	0.85	0.87	1.15
CHINA total	**1,073,032**	**3.86**	**0.85**	**0.88**	**1.10**
Physics	151,859	3.10	0.88	0.89	1.06
Environment/ecology	26,350	5.16	0.87	0.89	1.07
Psychiatry/psychology	4,820	4.32	0.90	0.92	0.92
Social sciences	13,424	5.20	0.93	0.94	0.95
Economics and business	6,809	5.95	0.95	0.95	0.96
Geosciences	31,551	4.10	0.98	0.96	0.91
Engineering	119,006	4.57	0.97	1.00	1.08
Mathematics	41,701	3.51	1.03	1.01	0.88
Agricultural sciences	19,087	7.91	1.02	1.03	0.94
Computer science	35,760	4.02	0.87	1.07	1.67

The impact of some rapidly growing areas of biomedical and molecular sciences are grouped around, or slightly below, China's average citation impact. These are areas where China is likely to benefit most from international collaboration, and where the UK research base is particularly strong. However, the value of interpreting the strength of broad areas of Chinese research in these terms is limited, as we noted earlier. It would be more valuable to drill down to the detailed view offered by the *Web of Science* fields and essential to consider institutional patterns in order to identify leading research groups. Table 8 provides some examples of particularly strong niche fields within the broader areas of science.

The strengths and weaknesses of China's research portfolio

We should be very cautious when interpreting strengths and weaknesses of the Chinese system with too broad a brush. Spikes of excellence (see p.38) and pools of mediocrity can be hidden among the averages. Analysis across the 256 finer grained *Web of Science* (WoS) journal categories needs to take careful account of varying field size, as well as the average citation impact and any trends (of output or impact) within each field. Because of the exceptional dynamics of the China research economy, a conventional SWOT analysis is almost meaningless. Using historical data to safely predict future strategic positions requires a steady state. For Chinese research, there are currently too many dynamic variables to allow for accurate predictions.

Table 8. **Examples of China's research strengths within major areas of the research base (2003–2012)**[148]

Essential Science Indicators journal category	ESI impact	*Web of Science* journal category	WoS impact	Papers	
				Total	Growth
Agricultural Sciences	1.03	***Horticulture**	1.35	2,081	3.5
		***Agricultural Engineering**	1.32	1,924	15.2
		Agriculture, Multidisciplinary	1.29	3,260	10.4
		Agronomy	1.20	4,517	3.2
		Food Science and Technology	1.12	8,372	8.9
Chemistry	0.87	***Electrochemistry**	1.33	12,503	6.0
		Organic Chemistry	1.17	20,615	2.6
		Analytical Chemistry	1.07	25,698	2.5
Computer Science	1.07	***Cybernetics**	2.00	1,054	1.7
		***Theory and Methods**	1.44	13,004	0.7
		***Hardware and Architecture**	1.40	3,300	2.3
		***Artificial Intelligence**	1.38	11,005	3.6
		Telecommunications	1.25	8,146	5.2
Engineering	1.00	***Instruments and Instrumentation**	1.36	8,607	4.1
		***Transportation Sci and *Technology**	1.35	1,514	3.8
		***Civil Engineering**	1.33	9,039	3.8
		Biomedical Engineering	1.31	4,948	4.5
		Automation and Control Systems	1.22	8,275	4.5
		Industrial Engineering	1.19	3,155	1.6
		Nuclear Science and Technology	1.14	3,995	2.3
		Environmental Engineering	1.13	8,837	6.9
Materials Science	0.86	Textiles	1.26	1,685	3.4
		Paper and Wood	1.22	590	6.2
		Characterisation and Testing	1.20	2,181	2.1
		Biomaterials	1.09	4,473	4.6
		Nanoscience and Nanotechnology	1.06	22,186	6.9
		Composites	1.06	4,784	1.1
Mathematics	1.01	Mathematics	1.14	22,671	2.4
		Applied Mathematics	1.07	33,539	2.7

Subjects starred and highlighted in bold are China's top 10 (ranked by impact) of all *Web of Science* categories where volume exceeds 1,000 papers in the period.

China's papers in 54 WoS fields have, across the decade, more than 1,000 papers and an average citation impact above the world average. A further 17 fields have smaller volume but also have an average normalised citation impact greater than world average. There are other fields that have surprisingly low citation impact.

In analysing publication volume and growth at this granularity, we again find a complex mosaic. Mathematics is high impact overall but some specialist areas (Mathematical Psychology, Mathematical and Computational Biology) appear weaker. Similarly, in Materials Science, both Composites and Ceramics are below world average but Textiles is well above (1.24).

EXAMPLES OF CHINESE RESEARCH AND TECHNOLOGY EXCELLENCE

- In June 2013, China took the number one spot in the TOP500, a twice-yearly ranking of the world's fastest supercomputers when the Tianhe-2 (or Milky Way-2) was successfully tested almost two years ahead of schedule.[149]
- In April 2013, material scientists at Zhejiang University announced the world's lightest material: a graphene aerogel that is 12 per cent lighter than the previous record holder.[150]
- China's manned submersible, the Jiaolong, set a new national dive record after reaching more than 7,000 meters below sea level in June 2012.
- BGI (formerly Beijing Genomics Institute, a spin out of the CAS Beijing Institute of Genomics) has gone from accounting for around 1 per cent of the world's gene sequencing capabilities in 1999 to almost 50 per cent today. BGI works with more than 10,000 collaborators from universities and industry around the world.[151]
- Beidou Satellite Navigation System (equivalent to the American GPS system) is now in service and aims to provide a global service by 2020.
- In October 2012, China unveiled Asia's largest mobile radio telescope in Shanghai to collect data from satellites and probes.[152]
- The Harbin-Dalian high speed railway, the first in the world capable of operating in areas of extremely low temperatures, began operations in December 2012.

Bibliometric data can be useful in devising strategies for international collaboration, but it is important to dig beneath the level of disciplines to understand the performance of individual institutions and research groups. At its best, the Chinese system has concentrations of output and excellence similar to those of a G7 nation. Fewer than 10 per cent of Chinese institutions collectively produce more than 50 per cent of papers (a similar picture to that of the UK). Overall in China, 100 institutions account for about 90 per cent of research activity, as reflected in publications. While China's largest and best-funded universities look increasingly like big civic universities in the UK in terms of their output profile, there are also niche pockets of excellence in medium size and smaller institutions. In the next chapter, we consider the distribution of research excellence in the context of China's fast-changing geography of innovation.

4: MANY CHINAS, MANY INNOVATION SYSTEMS

Over a thousand miles from the coast, Chengdu is a city of 14 million people with an ambition to become a global IT powerhouse. If you're reading this on an iPad, there's a good chance it was made in Foxconn's Chengdu factory.[153] The city is also becoming known for its software companies, with three of the ten most popular Chinese apps in 2012 developed by Chengdu–based companies.[154]

Chengdu's transformation from a regional backwater to a global economic powerhouse is startling: from $44.85 billion in 2006, its GDP hit $132 billion in 2012, larger than the whole of Hungary.[155] It has managed this transformation by attracting many of the world's top high–tech companies to set up in the city, including Dell, GE and Siemens.[156]

Second tier cities like Chengdu, Xi'an and Wuhan, have all benefited from a boom in infrastructure building as a result of government policies to develop central and western China, which has in turn led to investment flowing in from multinationals looking to take advantage of low wages and access rapidly expanding local markets.[157] As a consequence, these cities are increasingly moving up the innovation value chain. This suggests that the future geography of innovation in China will shift beyond the coastal regions.

For now, however, the bulk of innovation remains highly concentrated on the east coast. Just three east coast cities – Beijing, Shanghai and Shenzhen – accounted for over 31 per cent of all invention patent grants in 2012,[158] and the share of patents granted to applicants in the eastern region has grown over time, from 50 per cent in 2001 to 67.2 per cent in 2011.[159] East coast cities also produced over half of all papers published in *Web of Science* referenced journals in 2011 (with Beijing alone responsible for 25 per cent). The east coast region also received 64 per cent of all funding from central government S&T plans in 2011.[160]

This concentration of innovation inputs and outputs mirrors China's economic geography, which is characterised by a developed east coast and poorer inland regions. When Deng Xiaoping announced in 1985 that it was OK for some regions to get rich first, the coastal provinces took advantage of their natural advantages to leap ahead of the rest of the country. Now the same model is being applied to innovation, with the government calling for 'innovation resource–intensive regions to take the lead in achieving innovation–driven development.'[161] Coastal provinces have used their many innovation resources, including highly educated workers, clusters of universities and research institutes and low transportation costs to actively promote their regions, which has ensured that innovation inputs and outputs are highly concentrated in the east.[162]

Western regions on the other hand have a weaker environment for innovation, including lower levels of education. As a result, they face difficulties in winning government S&T projects on merit and also tend only to attract FDI for low–cost manufacturing, rather than R&D, which doesn't help them to become more innovative.[163] China's regional disparities are being exacerbated by the government's drive to place businesses at the centre of the innovation system,[164] as regional differences in R&D expenditure are greater between companies than between government agencies.[165] Furthermore, R&D intensive industries which were once compelled to locate in western China because of the military-industrial 'third line' construction project are now leaving these regions for more favourable conditions in the developed east.[166]

Figure 7: **Inputs to Chinese innovation: A geographic view**

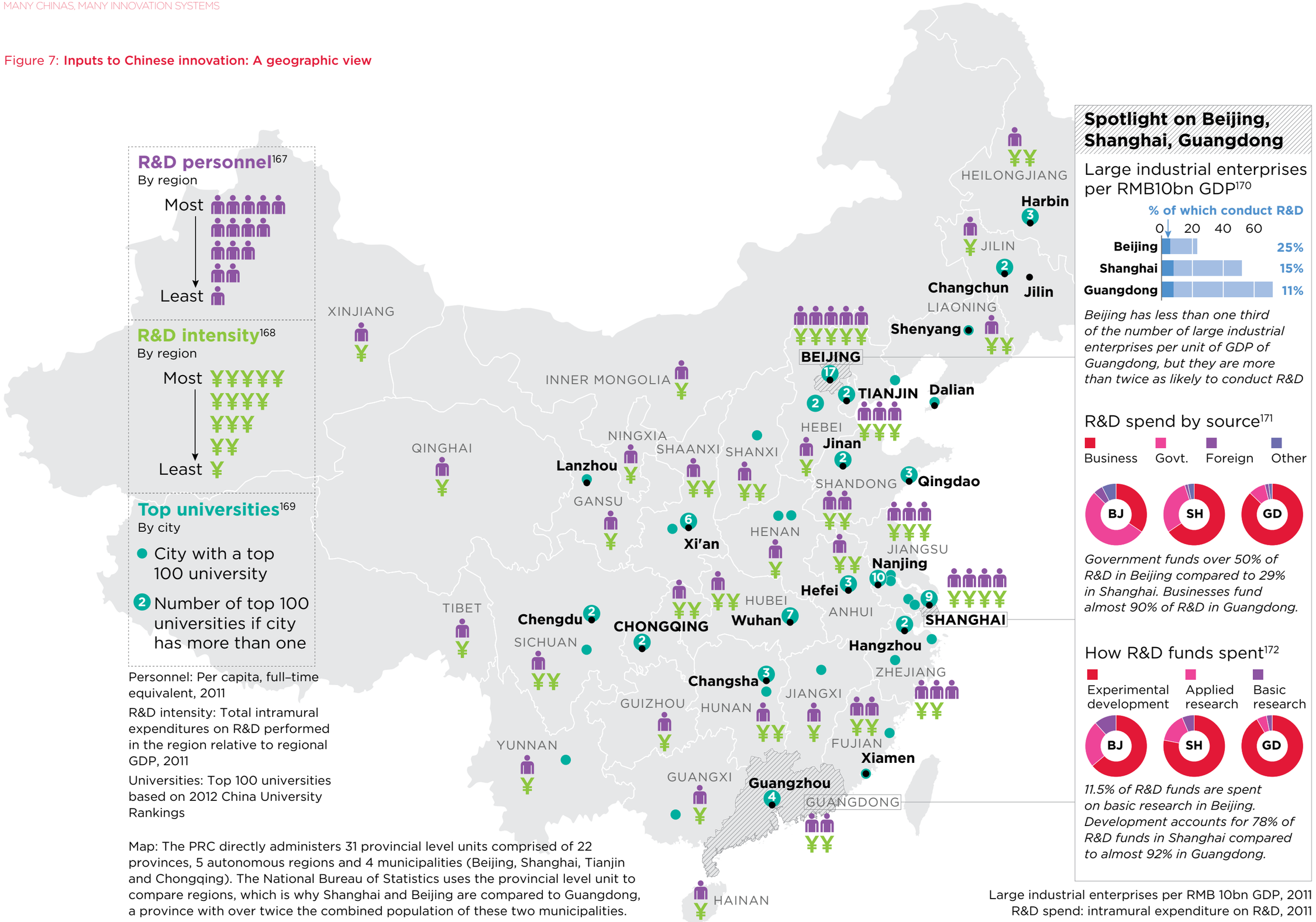
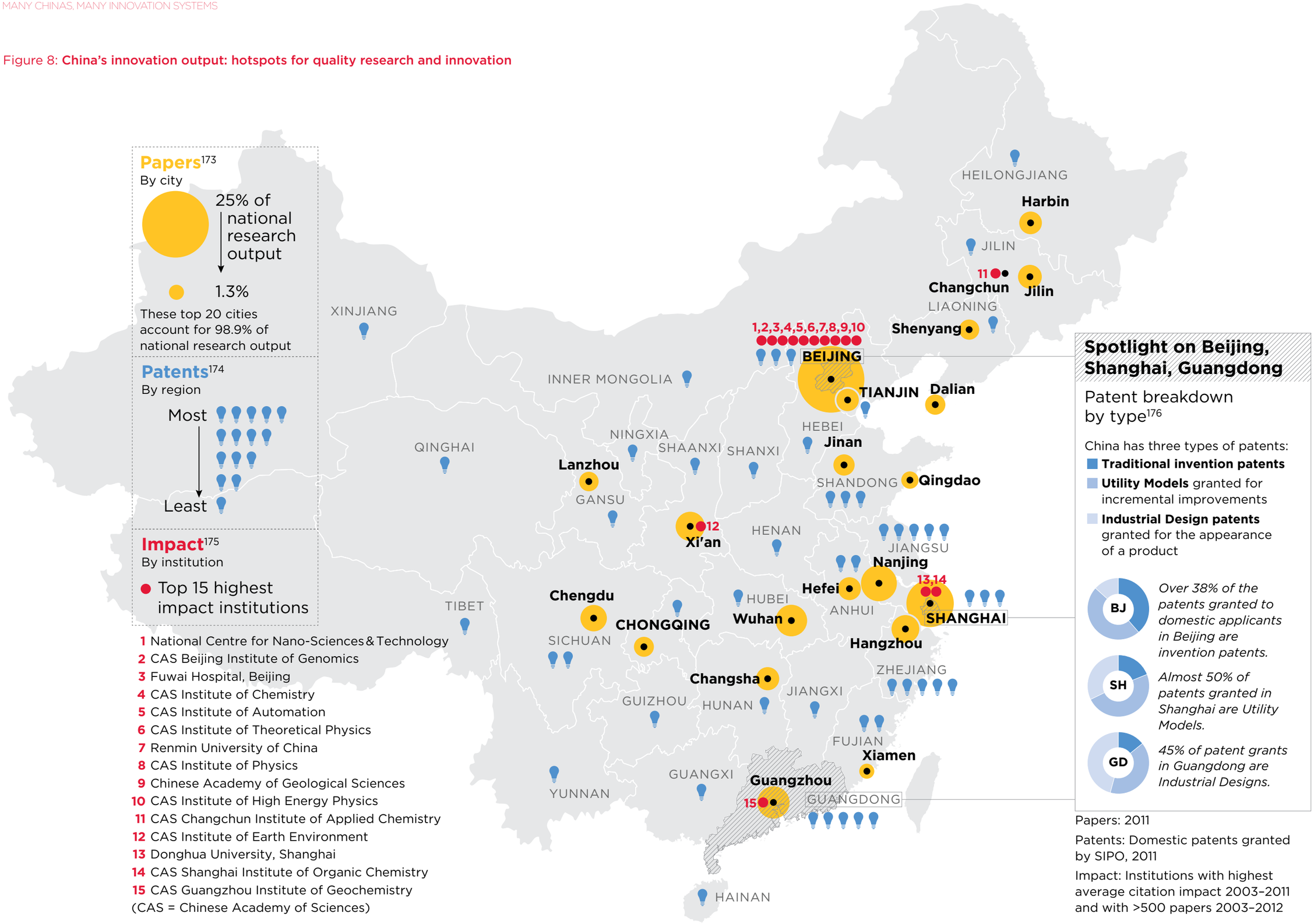


Figure 8: **China's innovation output: hotspots for quality research and innovation**



Regional models of innovation

China's national S&T plans do not set out detailed policies for different regions.[177] Instead, central government calls on regions to rely on their own 'distinctive innovation resources' and draw on regional characteristics to develop their innovative capacity.[178] Provinces also have a lot of spending power, with half of China's total S&T expenditure coming from provincial and local governments.[179]

This autonomy has resulted in experimentation with different models of S&T development. Innovation scholars Dan Breznitz and Michael Murphree describe this as *"structured uncertainty",* which they define as *"an agreement to disagree about the goals and methods of policy."* They argue that the ambiguity of much of Chinese policy *"leads to multiple interpretations and implementations of the same policy."*[180]

However, structured uncertainty has also lead to short–termism in the goals that businesses and policymakers pursue, as the vagueness of Chinese policy means that *"it is impossible under the force of structured uncertainty for any actor—political or business—to know ex ante what behaviors...will be encouraged or sanctioned."*[181] While these conditions have created unique models of innovation in Beijing, Shanghai and Guangzhou, discussed below, beyond these hotspots they have also led to the contradictory phenomenon whereby different Chinese regions have a tendency to follow the same development models, despite their unique endowments.[182] The World Bank believes this stems from the lack of a nationally coordinated innovation policy, which could ultimately hinder China's future economic development.[183]

Beijing

When Microsoft decided to set up an R&D centre in China, Beijing was the obvious choice of location. China's capital is home to 83 universities and colleges,[184] including China's two most prestigious universities, Tsinghua and Peking, and 41 of the 104 research labs of the Chinese Academy of Sciences.[185] Furthermore, 25 per cent of all papers published in WoS referenced journals come from Beijing.[186]

Beijing also invests more in R&D as a per centage of output than any other Chinese region, at 5.7 per cent, and in 2011 spent 93.66 billion RMB (US$15.3 billion) on R&D, over a third of the UK's total R&D spend.[187] As a result of the abundance of research institutes and universities in Beijing, over 50 per cent of R&D expenditure comes from the government,[188] which is significantly higher than other east coast regions. The large number of universities and research institutes also means that the reason why R&D spending is more focused on basic and applied research than other parts of the country.

Beijing's impressive educational and research resources are largely located in the north west of the city, in and around Zhongguancun Science Park. This cluster has spawned a vibrant industry of university spin outs, such as Lenovo and Founder group, private companies such as Baidu, venture capital firms and incubators such as Zhenfund and Innovation Works and has attracted many multinationals to set up R&D centres there, such as Intel and IBM. These R&D resources mean that Beijing is granted over twice the number of invention patents per capita than Shanghai.

Shanghai

Five hours down the coast by high–speed train, Shanghai has used its openness to multinationals and the strong support of state–owned companies to develop China's most

advanced integrated circuit cluster.[189] Shanghai's Zhangjiang hi–tech park is home to many of the world's most famous names in semiconductors, such as Nvidia and Intel, and China's largest state owned semiconductor foundries. As a result, the park accounted for 20 per cent of China's integrated circuit sales in 2010.[190]

While Beijing has a comparative focus on fundamental research, Shanghai has carved out a niche for itself in development–focused R&D to support its strong manufacturing base.[191] Yet the integrated circuit companies in Zhangjiang Science Park largely focus on manufacturing, testing and packaging ICs that are not at the cutting edge.[192] This manufacturing base is now under threat as companies like Intel move production inland in search of lower wages and it is not yet clear whether Shanghai's IC sector will be able to move into the higher value stages of value chain.

Shanghai's pharmaceutical sector is perhaps a more promising example of the way it will innovate in the future. Here again, openness has allowed it to attract the world's top pharmaceutical companies to set up R&D centres, including Roche, AstraZenneca and GSK. As in the integrated circuit industry, these have focused so far on development rather than drug discovery, but GSK's Shanghai operation is gradually moving to become its global centre for drug discovery in neurodegenerative diseases. This is complimented by universities such as Fudan (China's number three), where life sciences accounted for 40 per cent of its publications between 2003 and 2012.[193]

Shanghai's weakness is its lack of SMEs and private enterprises. While Beijing's Zhongguancun Science Park is dominated by small university spin outs and other start–ups, local government plans plus the lack of a university cluster have ensured that Shanghai's Zhangjiang Science Park is dominated by large state–owned enterprises and foreign multinationals.[194]

Guangdong

It is no coincidence that Huawei, one of China's most successful private companies and global innovation brands, was founded in Guangdong province. Guangdong is home to three of the six special economic zones set up in the 1980s to engage with the market economy and the outside world.

In their book *Run of the Red Queen,* Dan Breznitz and Michael Murphree argue that the influence of the state on the direction of economic development – a strong feature of both Shanghai and Beijing's innovation systems – is largely absent in Guangdong. It has taken a more hands off, unplanned approach, relying on foreign investment to flow into the most profitable industries. The result has been a strong focus on manufacturing and assembly for export, particularly in IT and telecoms.[195]

This strategy has served Guangdong well, making it China's richest province. But a combination of falling exports as a result of the financial crisis of 2008 and manufacturers relocating inland in response to wage inflation have hit Guangdong hard and resulted in thousands of factory closures and millions of job losses.

Application–focused R&D, which Guangdong is particularly strong in, may be the key to its future innovation model. Guangdong has traditionally been weak in basic research, with few world–class universities. R&D spending by businesses accounts for a larger proportion of total R&D than in any other region. This has led to practical, application focused R&D, and is the reason why Guangdong was granted 15.4 per cent of all invention patents in 2012 (almost double the share granted to Shanghai).[196]

The role of innovation clusters and science parks

There is limited evaluation of the impact of science parks on innovation in China, but it's clear there is a good deal of diversity in quality and impact. Some believe that science parks are largely focused on manufacturing and assembly and do not engage in research or innovation.[197] However, others argue that science parks have a much broader role: they attract FDI, facilitate knowledge dissemination, and integrate regional activities into global value chains, which ultimately leads to technology upgrading and stimulates innovation.[198]

Local governments are also keen to stimulate innovation within existing industrial clusters and provide funding and advice to that end with mixed success.[199] The central government in 2013 announced the first batch of ten pilot innovative industrial clusters to stimulate innovation and industrial competitiveness within clusters and stimulate industrial upgrading of the industries located there.[200] The plan states that a new batch of innovation clusters, which are to be based within existing national high–tech zones, will be announced each year. The first batch of innovation clusters are listed in Table 9.

Table 9: **The first list of innovative industry cluster pilots**

Cluster location	Focus
Beijing Zhongguancun	Mobile Internet
Baoding	New energy and smart grid equipment
Benxi	Pharmaceuticals
Wuxi New District	Intelligent sensing systems
Wenzhou	Lasers and Optoelectronics
Weifang	Light–emitting semiconductors
Wuhan East Lake High–tech Zone	National Geospatial information and application services
Zhuzhou	Innovative rail transportation equipment manufacturing
Shenzhen High–tech District	Next–generation Internet
Huizhou	Cloud computing and smart terminals

The role of universities in regional innovation

Unlike many developed countries, universities in China are significant sources of patents as well as publications. Universities account for six of the top ten domestic Chinese institutions which were granted the most invention patents in 2012. And they are highly concentrated in activity: all but one of these is on the east coast.[201] Research output is similarly concentrated on the east coast, which is home to eight out of China's top ten most productive universities and all 15 of the institutions that produce the highest impact research.[202]

Table 10. **The ten Chinese universities (+CAS) with greatest publication output 2003–2012**[203] (average normalised citation impact, 2003–2011, pink indicates above national average)

	Output	% China total	Impact
Zhejiang University	41,053	3.83	0.89
Tsinghua University	38,530	3.59	0.95
Chinese Acad Sciences, Graduate University[204]	37,121	3.46	0.95
Peking University	35,944	3.35	1.06
Chinese Academy of Sciences[205]	34,242	3.19	1.05
Shanghai Jiao Tong University	33,757	3.15	0.86
Fudan University	25,264	2.35	1.00
Nanjing University	23,562	2.20	0.94
University of Science and Technology of China	21,970	2.05	1.14
Sichuan University	20,071	1.87	0.75
Sun Yat-sen University	19,505	1.82	0.99
Shandong University	18,866	1.76	0.83

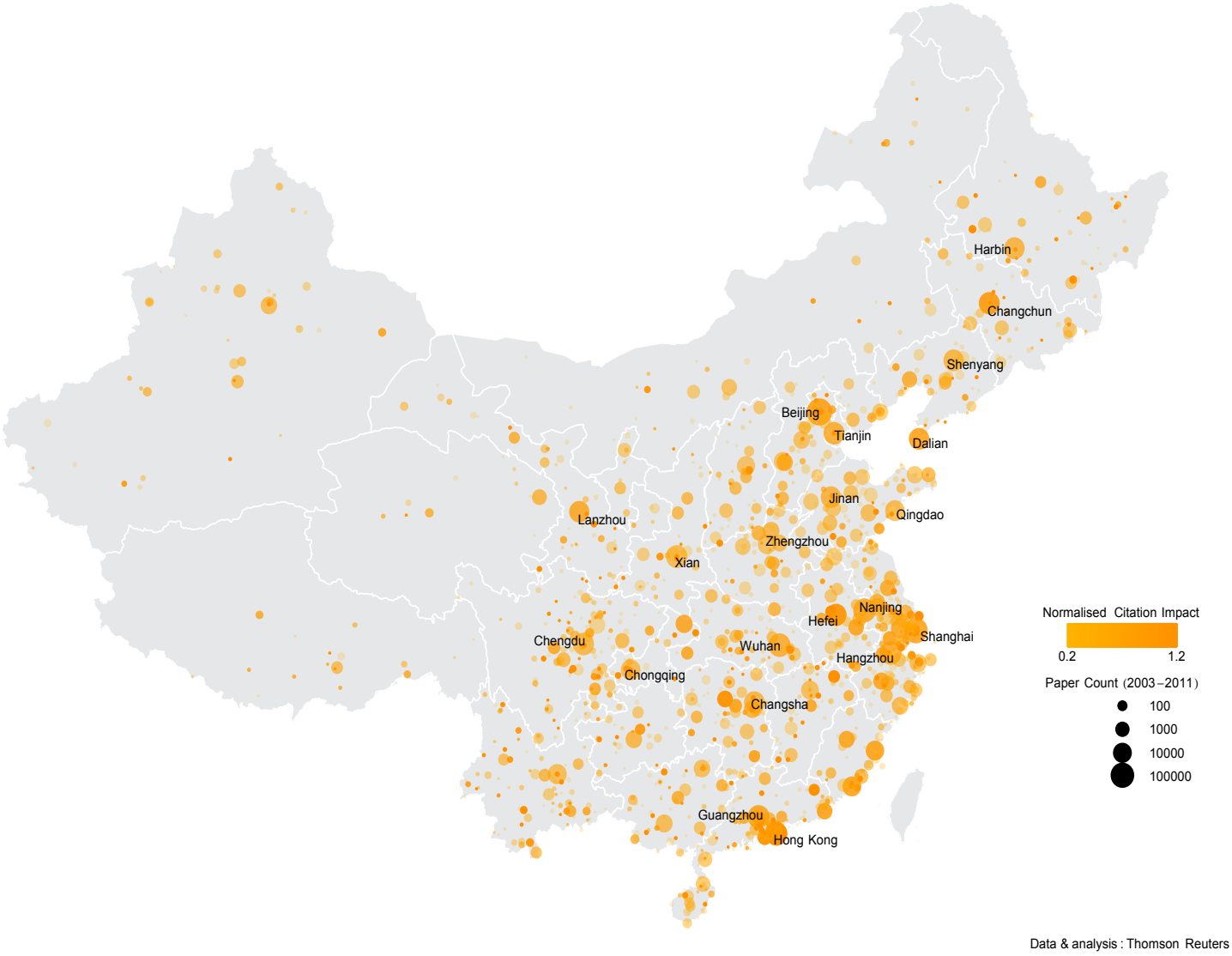
Table 11. **China highest average citation impact institutions 2003–2011 and with >500 papers 2003–2012.**[206] Pink indicates normalised citation impact above the national average

These institutions are pinpointed on the map on page 41.

	Output	Impact
National Centre for Nano-Sciences and Technology	963	2.09
Chinese Academy of Sciences/Beijing Institute of Genomics	593	1.97
Donghua University, Shanghai	1,484	1.76
Fuwai Hospital, Beijing	760	1.48
Chinese Academy of Sciences/Guangzhou Institute of Geochemistry	2,021	1.48
Chinese Academy of Sciences/Institute of Chemistry	7,856	1.45
Chinese Academy of Sciences/Changchun Inst Applied Chemistry	6,571	1.41
Chinese Academy of Sciences/Shanghai Inst Organic Chemistry	4,390	1.41
Chinese Academy of Sciences/Institute of Automation	1,093	1.38
Chinese Academy of Sciences/Institute of Theoretical Physics	1,984	1.33
Chinese Academy of Sciences/Institute of Earth Environment	749	1.32
Renmin University of China	1,610	1.32
Chinese Academy of Sciences/Institute of Physics	7,320	1.29
Chinese Academy of Geological Sciences (CAGS)	2,061	1.28
Chinese Academy of Sciences/Institute of High Energy Physics	4,470	1.27

The ranking of the most research intensive cities is largely unchanged since 2003. However there has been an increase in activity and impact away from the traditional centres on the east coast. Figure 9 represents the spread and intensity of research across China since 2003.

Figure 9. **City-level distribution of research volume and impact in China, 2003-2011**[207]
Size of bubbles indicates relative number of papers; intensity of orange indicates relative average citation impact.



Future regional patterns of innovation

Two conflicting processes are at play across China's innovation landscape. There is still a marked concentration of high–end outputs on the east coast, and its existing advantages give it a greater capacity to absorb knowledge and S&T funding. The government's drive to place businesses at the centre of the S&T system is exacerbating regional concentrations of activity, as companies move to regions which have the best human capital and environment for innovation. A counter current to this is the steady flow of labour intensive manufacturing away from the east coast, which could eventually lead to technology upgrading and stimulate innovation.

The east–west dichotomy is insufficient in explaining China's geography of innovation, given the very different models of innovation across east coast cities and provinces. For instance, Beijing's system is more focused on basic and applied research, driven by intensive government funding a strong university cluster. This compares to Shanghai's government–driven focus on experimental development linked to a strong manufacturing base. In contrast, Guangdong's approach is more private sector driven, with over 90 per cent of R&D funding from business. While the central government sets the overall policy context, targets and evaluation metrics, there is a considerable degree of autonomy in how to deliver on these goals, leading to very different interpretations of national policies. Even among China innovation analysts, opinions differ on whether reform is likely to lead to a greater degree of local autonomy and experimentation (e.g. Breznitz et al.) or whether in contrast we are likely to see a tightening up of central coordination to tackle the inefficiencies espoused in this approach (e.g. Cao et al.) In the next chapter, we consider the role that business and enterprise can play in this changing innovation mix.

5: THE ENTERPRISE OF INNOVATION

Baidu, the Chinese internet search company, announced in early 2013 that it would be setting up an artificial intelligence research lab in Cupertino, Silicon Valley later this year. Its Institute of Deep Learning (IDL) will seek to 'simulate the functionality, the power, the intelligence of the human brain.' This is a bold move by one of a cadre of leading Chinese companies, and is modelled in some respects on the investment in basic research in an earlier era by corporate giants like Bell Labs and Xerox PARC.

Yet China's answer to Google still has a long way to go to shake its reputation as an imitator of its American counterpart. China's technology scene is packed with so-called 'C2C' (Copy to China) companies, and importing, absorbing and digesting technologies and business models remains a prevalent feature of Chinese business. Some see this as a learning phase in the development of a business-led innovation system, but others suggest that China's model of rapid adoption and absorption is fast becoming a value-adding specialism that will persist alongside more pioneering endeavours like those of Baidu's IDL.

In this chapter, we highlight the role of China's vanguard global innovators, and review how entrepreneurship and innovation have developed in recent years across the rest of China's business sector.

Global innovation brands

In 2008, the Booz and Company ranking of the leading 1,000 business R&D investors featured 15 Chinese companies. By 2012, 47 companies made the list (compared to an increase from four to nine Indian companies over the same period).[208] Baidu ranks sixth in *Forbes* magazine's analysis of the world's most innovative companies, while fellow technology firm Tencent comes in at number 18.[209]

Although the methodologies for rankings like these vary widely, there's no doubt that a growing cadre of Chinese companies are now operating at the technological frontier. According to the World Intellectual Property Organisation, the ICT giant ZTE applied for more patents (PCT) in 2012 than any other company worldwide. Huawei came a close fourth in the global rankings.[210]

Global leaders are not confined to ICT. In a supporting analysis as part of its *China 2030* report, the World Bank highlights the additional examples of Chinese excellence in *"auto assembly and components, PVCs, biopharmaceuticals, nanotechnology, stem cell therapeutics, high density power batteries, high-speed trains, telecommunication equipment, wind turbines, single aisle passenger aircraft, booster rockets, space satellites, supercomputers, shipping containers, internet services, and electric power turbines."*[211]

China's ongoing but incomplete transition to an enterprise-led innovation system since 1978 has been well documented by international agencies like the World Bank and OECD.[212] Rapid growth in R&D expenditure has largely been driven by the enterprise sector, which accounted for an above-OECD average 75 per cent of China's R&D spend in 2011, compared to only 27 per cent in 1990 and 60 per cent in 2000.[213]

The role of state–owned enterprises (SOEs)

Understanding which businesses are driving innovative performance is somewhat clouded by the significant proportion of R&D expenditure by state–owned and state–controlled enterprises. As the table below suggests, they play a key role in certain technological areas such as high–speed rail and telecoms, although most SOEs operate outside of the most strategic emerging technology sectors.[214]

Table 12: **Top companies by R&D spending and type of ownership (2010)**[215]

Source: *State Enterprises: Reform or Die?* Denis Simon (2012)

Rank	Company	Ownership status	R&D spend (bn RMB*)
1	**Huawei Technologies**	Private	16.6
2	**China Mobile Communications Corporation**	State	13.6
3	**China Aerospace Science and Technology Corporation**	State	13.0
4	**China National Petroleum Corporation**	State	9.4
5	**Shanghai Automotive Industry Corporation**	State	9.3
6	**China Shipbuilding Industry Corporation**	State	9.2
7	**China Railway Construction Corporation**	State	8.8
8	**China Aerospace Science and Industry Corporation**	State	8.5
9	**China Petroleum and Chemical Corporation**	State	7.1
10	**ZTE Corporation**	Private	7.1

*1 billion RMB = US $163 million

Table 11, reproduced from a paper by Denis Simon, an expert on China's S&T policies, lists Huawei and ZTE as private companies. However, there has been much speculation around Huawei's links with the Chinese government, and while ZTE is a public company listed in Hong Kong, its main shareholders are a Chinese SOE and a former army unit.[216] This underlines the importance that the state and state–owned companies play in China's innovation system.

The most profitable are the so–called 'central SOEs', the 117 firms administrated by the State–owned Assets Supervision and Administration Commission (SASAC), which control assets equalling over 60 per cent of the country's GDP.[217] Eighty–eight of the 95 Chinese companies which made the 2013 Global 500 list of the world's richest companies are SOEs. Two of these companies alone, China Mobile and China National Petroleum Corporation reported greater 2009 profits than China's 500 most profitable private companies combined.[218]

However, according to a controversial report from the Unirule Institute of Economics, a Chinese think tank, large subsidies have masked the performance of the vast majority of SOEs. Unirule calculates that, if all state subsidies were deducted from SOE returns, the average return on equity from 2001 to 2009 would have been –6.29 per cent.[219] SOEs accounted for 45 per cent of in–house R&D in industrial enterprises in 2009, and dominated spending on absorption and adaptation of foreign technology,[220] but aren't usually good at converting this into innovation output as measured by patents. According to an extensive World Bank survey, their R&D is likely to be unproductive and poorly integrated with the rest of their operations.[221]

Table 13: **Patents applications and R&D performance of Industrial Enterprises, 2011**[222]

	Patent applications	R&D expenditure per patent application (RMB)
State-owned enterprise	20,746	2,225,082
Private-owned domestic funded enterprise	111,705	845,083
Enterprises with funds from Hong Kong, Macao and Taiwan	41,595	1,347,334
Foreign funded enterprise	52,711	1,776,003

Source: China National Bureau of Statistics, 2012 Statistical Yearbook

SOEs control significant physical assets and human capital stocks and dominate FDI networks. While this results in pressure from national policymakers to reform and invest in R&D, a powerful elite within the SOEs is strongly incentivised to maintain the status quo. The monopoly position of many SOEs is also a considerable disincentive to innovate. Although consolidation and privatisation over the last few decades have enhanced the performance of many SOEs, there is an ongoing debate about the course of future reform for the more than 100,000 such entities which remain.[223]

Analysts point to a trend of increased SOE openness towards investment, risk assessment and talent procurement that might increase effectiveness if sustained.[224] While there is often concern about the role of heavily subsidised companies in creating unfair grounds for international competition,[225] research has also explored the innovation-limiting effect of SOEs on small private companies in China. Advocates of reform hope that abolishing many of the perks enjoyed by SOEs would stimulate innovation and entrepreneurship among credit-disadvantaged private-sector SMEs.[226] The government's recent 2013 'mini-stimulus package' is seen as a step in the right direction – creating credit streams and cutting taxes directly for SMEs (unlike the earlier 2008 stimulus package which was channelled through SOEs).[227]

Financing innovation: support for innovative small business

The Chinese banking sector has not historically provided a supportive environment for innovation in small firms, and bank credit is tough to obtain for non state-owned companies. Direct public support to business R&D is also limited.[228] Recent efforts to boost business R&D include significantly reducing corporate tax rates for high-technology companies, as well as an R&D tax credit introduced in 2010.[229]

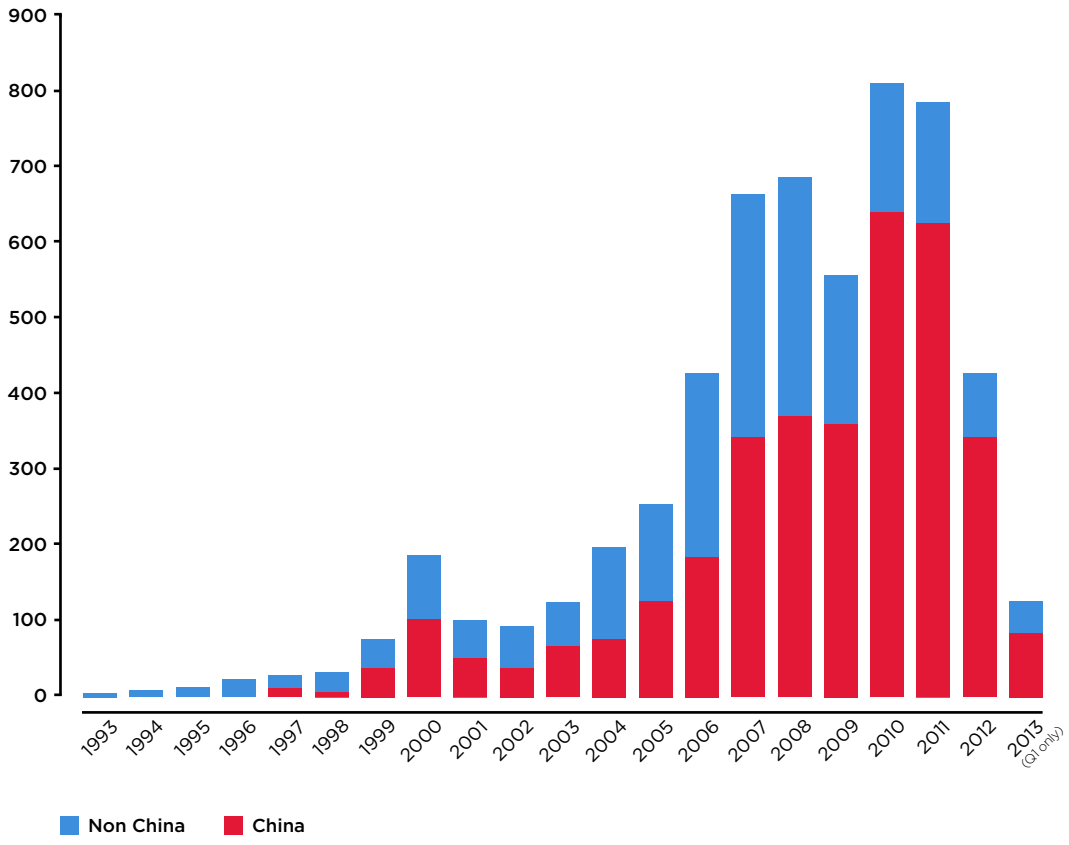
A major part of institutional efforts to support start-ups is the Torch Programme. As of 2011, 89 high-tech zones are overseen by this national programme to develop high-tech industries, which has been in operation since 1988.[230] While exact support varies from region to region, these zones contribute well over a third of national industrial output. Zhongguancun Science Park in Beijing is one such zone. It houses 41 colleges and universities, 206 research labs,[231] 67 state level key labs, 14,929 enterprises, over 400,000 S&T personnel[232] and receives over one-third of Chinese venture capital investment.[233]

In recent years, the early-stage capital provided by the Torch programme and the Innovation Fund for Small Technology Based Firms[234] (operational since 1999) has been supplemented by a growing venture capital industry. As of April 2012, 86 'VC leading funds'

– through which government provides investment guarantees, risk subsidy and follow–on investment – have been founded in China, with a collective capital of RMB 53.17 billion (US$8.69 billion). With over 100 firms registered in 2006, following the introduction of a favourable tax policy in 2007, the China Venture Capital Association now lists 882 VC firms. These are concentrated on the east coast.[235] Recent analysis by Thomson Reuters suggests that while VC investment remains concentrated in the Bohai Region (which is centred on Beijing and Tianjin), the Yangtze River Delta Region (Shanghai, Jiangsu province and Zhejiang province) and the Pearl River Delta Region (Guangdong Province), activities are also expanding into Central and Western China. In these locations the competition for deal flow is less fierce and more favourable governmental incentives are available.[236]

Funding is more likely to be at growth stage than seed stage. Global VC investment into China is also growing fast, particularly in healthcare and IT sectors. Until 2010, European companies consistently attracted more than double the VC investment of Chinese companies. As of 2011, Europe is only slightly ahead and is not expected to maintain its lead.[237] An unfavourable global economic outlook has meant that VC investment slowed significantly in 2011–2012, but early indications are that the market is picking up again so far in 2013.

Figure 10: **Venture capital investments by year and origin**



Taken from Thomson One Investment Analytics database (July 2013)

Flows of foreign technology

Although a focus on the attraction and absorption of foreign technology and ideas may seem at odds with the push for more home–grown, original innovation, in fact both are critical strands of China's story. The role of foreign technology in China's innovation system is evolving rather than diminishing.

World Bank data shows that in 1996, large and medium Chinese enterprises were spending almost 1.2 per cent of their revenue on the acquisition of foreign technology, whereas in 2006 that had dropped to less than 0.2 per cent. Conversely, expenditure on R&D went from 0.4 per cent in 1995 to 0.8 per cent in 2006.[238]

While China's trade surplus in high–tech goods is growing,[239] its balance of payments deficit for the use of foreign IP is also on the rise. World Bank data shows that in 2012 it received just over $1 billion in fees,[240] but paid out over $17.7 billion, leading to a deficit of $16.7 billion. This compares to a payments surplus of over $80 billion in the USA.[241]

Much analysis has been devoted to the increasing numbers of multinational R&D centres which levy a significant proportion of these charges. Estimates of the exact number of foreign–invested R&D centres in China vary, but according to official statistics from the Ministry of Finance there are now over 1,800 – more than double the number estimated in Demos' 2007 study.[242] These are now estimated to account for about 20 per cent of China's R&D spending.

The primary effect of importing foreign technology has been the dramatic expansion of China's manufacturing capacity.[243] However, it is well established in the innovation literature that such technology flows only lead to positive spillovers and productivity growth when the system has the capabilities and skills to absorb them.

Less analysis has been devoted to the recent growth in acquisitions of foreign R&D–intensive companies. In a recent article for the *Harvard Business Review,* Peter Williamson describes how a buying spree was initially triggered by China's accession to the WTO in 2001, reinforced by then Premier Wen Jibao's 2004 call on enterprises to 'go global'. From $1.63 billion in 2003, Chinese cross–border mergers and acquisitions (M&A) peaked at just over $73 billion in 2008 before the global financial crisis.[244]

While many early efforts to buy global brands and reputations ended in failure, Williamson suggests this was an important learning phase, and a new wave of M&A is now focused on 'concrete assets such as mineral deposits and state of the art R&D facilities'.[245] The motives for acquisition are as much about increasing domestic competitiveness as entering foreign markets. While it may not be surprising that Chinese companies have an interest in purchasing 'distressed companies with advanced technology,'[246] accessing the know–how, training and management expertise within those companies is becoming just as important as obtaining core technologies.[247]

Incremental innovation at hyper speed

There is also growing interest from analysts in the quality and speed of incremental innovation. OECD analysis suggests that Chinese companies spend far more on technology renovation (defined as 'the application of the latest technology to existing products, technology and equipment to improve production efficiency and quality') than on R&D.[248] These 'incremental' efforts to adopt and adapt the latest technologies have been an important driver of China's industrial development. While some analysts may be sceptical

of the longevity of these strategies for economic growth, others see them as an essential feature of China's global competitiveness in technology. As Breznitz and Murphree describe, *"Chinese technology companies shine by developing quickly enough to remain at the cusp of the global technology frontier without actually advancing the frontier itself."*[249] This is a particularly valuable specialism as global value chains in research and development become more fragmented, with growing opportunities to capture the value of innovations a long way from the point of creation or conception.

The global energy giant BP has long–standing collaborations with China spanning the full spectrum of its innovation interests. Collaborative projects in China include a fundamental chemistry lab in Dalian; energy policy research with Tsinghua University; a Shanghai R&D lab; a clean energy commercialisation centre working on technology deployment; and a corporate venturing arm that has been operational for five years.

Steve Cook, Strategy Advisor at BP, explains that while there are a range of motivations for each of these projects, China's specialism in rapid experimentation is often undervalued as a benefit by foreign companies: *"China is a great place to be empirical and learn by doing. The government is very keen to promote innovation and so small Chinese companies can get hold of factories rent free...There are also lots of service industries supporting this innovation drive. For example, it's 10–20 times cheaper in China to build a prototype production line. It's so cheap it's almost disposable. This means you can experiment. There is a boiling cauldron of people just trying stuff."*[250]

The blurring line between imitation and innovation

This 'boiling cauldron' includes a wide range of practices. One approach that has attracted some international attention is 'shanzhai.' Originally a term denoting bandit strongholds outside government control, today this is used to refer to businesses based on fake or pirated products.

Until recently, shanzhai companies have been regarded as a negative influence on Chinese innovation, a source of substandard product 'knock offs' which openly infringe other companies' IP rights. Yet others argue that shanzhai can be seen in a more positive guise, as a method that involves rapid iteration and adaptation, a deep understanding of user needs and often sophisticated manufacturing value chains. The consultancy Booz and Company suggests that shanzhai reflects a culture of 'fearless experimentalism' among Chinese manufacturers, and cites several cases of shanzhai companies evolving into disruptive innovators including the battery and car manufacturer BYD.[251]

Similarly, in a 2010 special report on emerging economies, *The Economist* highlights the high levels of skill required to produce rapid copies of high–tech gadgets like smart phones at low cost, and to add new features like telephoto lenses or solar chargers that distinguish a product from its competition. While these bandit innovators are in some senses 'parasites,' in others '(they) deploy as much innovation and ingenuity as their legitimate counterparts.'[252]

Some business magazines already recommend the use of shanzhai methods by Western companies.[253] Innovation scholars in China and the West are also trying to better understand positive lessons from shanzhai innovators.[254] For Yonjiang Shi at the Cambridge Institute for Manufacturing, the phenomenon demonstrates the value of densely networked manufacturing clusters that support new market entrants, and the importance of a strong manufacturing base for absorptive capacity in innovation.[255] For Keane et al., these

'renegades on the frontier of innovation' should be recognised as the leading edge of china's creative economy; experts in a kind of rapid prototyping that is often absent from larger companies.[256] Outside of manufacturing, some argue that shanzhai processes are now operating in other sectors, such as internet services and digital technology.

Making indigo from blue

As China's digital economy has grown at breakneck speed, shanzhai practices appear to have become just as prevalent there. Examples include Taobao (the Chinese Ebay), RenRen (the Chinese Facebook) and Sina Weibo (the Chinese Twitter).[257] In a recent study of Chinese technology entrepreneurship, Anna Maybank describes how copying is part of the development culture of the Chinese start–up community. A company learns by copying others, then iterates rapidly until it has a better or more locally effective product.[258]

It was still seen by some as controversial when Chinese internet services giant Tencent – now the world's third largest publicly traded internet company – was described by the magazine *Fast Company* as one of the world's 50 most innovative companies.[259] Tencent's 'QQ' instant messaging service started out as a direct copy of AOL's 'ICQ' service. Yet unlike AOL, Tencent quickly learnt how to generate a revenue stream from QQ users, by permitting them to buy items of clothing for their chat avatars. Tencent was one of the pioneers of in–game payments, long before Silicon Valley's Zynga hit upon the idea.[260] In 2007 it invested 100 million RMB ($16.34 billion) in setting up the first Chinese internet research institute. It now describes 50 per cent of its employees as R&D staff, and is hotly tipped to expand overseas with services such as WeChat, which 'shares many features' with the better known WhatsApp.[261]

WeChat now counts 300 million users, more than 70 million of whom are outside mainland China. Unlike WhatsApp, WeChat is rapidly expanding into online payments in a market that is due to triple in size between 2011 and 2015.[262] Anna Maybank's research with the Chinese tech community characterises this imitation first, innovation later strategy as 'making indigo from blue' – creating added value rather than a sub–standard copy. As one of her interviewees describes *"You don't have time to not copy. The pace is so fast. Economic growth is happening so fast. If you're not quick enough, someone else will."*[263]

China's internet services industry is growing at over 20 per cent a year, and its number of internet users is increasing at almost 22 per cent a year.[264] This growth alone accounts for 246 million new internet users between 2007 and 2010 (with equivalent growth over this period in the US of only 22 million). While we're likely to see many more cloned products being sucked in to this vortex of activity and scaled up, China is also set to become the source of far more breakthrough internet applications and services.[265]

The internet services sector exemplifies China's skilled absorption of ideas from around the world. A fast–changing sector with a burgeoning number of high quality private companies, it represents some of the most exciting aspects of China's innovation system. While China's internet companies have thrived despite the challenges posed by the 'Great Firewall,'[266] the world's most extensive internet censorship operation, some argue that the recent governent campaign against 'online rumours', which has resulted in many arrests, threatens the future of some of China's most innovative internet service companies.[267]
In the digital economy, as in other emerging sectors, the next decade is likely to see this top tier of Chinese companies further cement their global brand presence, expand their international markets, and combine expanding in–house R&D capabilities with an existing and rapid capacity to absorb and adapt ideas from elsewhere. For the UK, the strategic question is what role our companies and innovators should play in this process; in working with Chinese partners to make indigo from blue.

6: REBALANCING GROWTH

At a press briefing following the most recent US–China Strategic and Economic Dialogue, Lou Jiwei, China's finance minister, raised the eyebrows of his American audience when he said that China was aiming for a 7 per cent growth rate in 2013. Until that point, the official target had been 7.5 per cent, (itself a notch below the 8 per cent target, which held firm until 2011, giving rise to the official mantra 'baoba' or 'maintain eight'). The following day, China's Xinhua news agency quietly revised the minister's remarks back up to 7.5 per cent. It may simply have been the jet lag talking, but as the *Financial Times* reported: *"Mr Lou's mistake was in fact deeply revealing: China's official growth target is manifestly less important in Beijing today than at any time in the past decade."*[268]

Six years earlier, Wen Jiabao as premier acknowledged that China's economy was increasingly 'unstable, unbalanced, uncoordinated and ultimately unsustainable.'[269] These came to be known as the 'Four Uns', and the 12th Five Year Plan was directed towards tackling them. Growth is certainly weakening: the latest GDP figures suggest that 2013 may be the first year since the 1997 Asian financial crisis when China fails to meet its official targets.[270]

After three decades of rapid economic growth, debate is intensifying about how its economy can be rebalanced, and how growth relates to social progress and environmental sustainability. Stephen Roach, former Chairman of Morgan Stanley Asia, describes how *"China is at an important juncture in its development journey. It is determined to move away from the quantity dimension of growth to a new focus on the quality of economic development. This is not only about a downshift in GDP growth: it is also a critical shift toward the long dormant Chinese consumer."*[271]

China's economic rebalancing will have significant implications for the future of its innovation system. This chapter explores three dimensions of this shift:

- Towards more demanding, empowered consumers and the growth of user–driven innovation;
- Towards a sharper focus on resource consumption, environmental impacts, and the need for low–carbon and sustainable innovation;
- Towards a more vocal and proactive civil society, which is calling for new forms of social innovation.

Consumer and user–driven innovation

The rates of growth described above mean that by 2020 China's GDP will account for 19 per cent of world economic output, up from just 9 per cent in 2010. But what will be different about the next phase of growth is that it will be predominantly driven by domestic consumption, rather than exports and investments.[272]

While the average per capita spending power of Chinese consumers is forecast to remain relatively low for some time to come, the GDP of many of China's leading cities already equals that of entire European economies. McKinsey's research on Chinese consumer markets reveals that the upper middle class, the proportion of the population that drives

consumer spending and shapes product preferences will grow from 14 per cent in 2012 to 56 per cent by 2022.[273]

There are many implications of this shift in consumer spending power, but two stand out as far as innovation is concerned: first, how consumer markets are shaping the demand for innovation; and second, how companies are tapping the innovative power of consumers as a source of competitive advantage.

Consumer–focused multinationals have long been conscious that their future is likely to hinge on the Chinese market. Healthcare is a prime example. China's national spending on healthcare is predicted to hit $1 trillion in 2020, up from $357 billion in 2011.[274] According to McKinsey, since 2006, 13 of the top 20 pharmaceutical multinationals have established R&D centres in China, and global medical device companies like GE and Johnson & Johnson are all looking to grow their market share.

Yet market access can be complex, and multinationals are learning that regional interpretations of national plans can lead to diverse local markets. Huge volume markets, increasingly demanding consumers and fierce competition is likely to fuel experimentation and innovation within the sector. And with China's population of over 65s due to double by 2030 to 223 million, the prospects even within 'niche' sectors can look dramatic.

A different angle on the role of consumers in Chinese innovation is how companies can actively use consumer knowledge, input and feedback to shape the innovation process: what is commonly referred to as user–led innovation.[275] There have been several high–profile examples of Chinese companies getting this right. For example, the extraordinary growth of consumer goods company Haier has been driven by experimentation in niche markets based on consumer feedback.[276] In the late 1990s, the company received a series of complaints from customers in Sichuan province that washing machines were becoming clogged and breaking down. On investigation, the cause was revealed to be farmers using the machines to wash sweet potatoes.[277] In response, Haier created a new washing machine that, in addition to washing clothes, had a cycle that cleaned potatoes, fruit and shells. The first 10,000 machines were sold almost overnight.

Tech company Xiaomi is another example of a company tapping user development capabilities and feedback to inform its innovation strategy. The extraordinary growth this private company has demonstrated since it was founded in 2010 has seen it valued at over $10 billion USD in 2013. Developing high–spec mobile phone handsets for sale at low cost, it provides added services and applications on a customised platform in a similar approach to Amazon's Kindle offering. Often referred to as the 'Apple of China', its growth trajectory is supported by harnessing the power of user–feedback combined with innovative marketing. Xiaomi handsets use a customised version of Android called MIUI that their engineers update on a weekly basis with features suggested by a huge and loyal customer following.

Another potential area for user–led innovation in China is 3D printing. Astronauts on China's Shenzhou spacecraft recently perched on 3D printed seats, and in August 2013, Chinese scientists announced the creation of 3D bioprinted organs.[278] While it is unclear whether 3D printing will live up to its revolutionary hype, there is consensus that so called 'mass customisation' – manufacturing of niche prototype products in small batches by both experts and home enthusiasts – could be a significant source of new product innovation. After a slow start, 3D printing is likely to take off in China as much as it has in the more developed economies of Japan, US and the UK. At the 2012 World 3D printing conference in Beijing, Luo Jun, CEO of Beijing's Asian Manufacturing Association (AMA), predicted that revenues from Chinese 3D printing companies will reach 10 billion RMB (US $1.6 billion)

within three years.[279] The AMA plans to build 3D printing innovation centres in ten cities across China, and the technology has now been incorporated into a national strategy by the Ministry of Industry and Information Technology.

Low–carbon and sustainable innovation

In his final speech to the National People's Congress in March 2013, Wen Jiabao spoke of the 'sharpening contradictions' between economic growth and the environment. These are contradictions of which China's citizens are only too aware. Sixteen of the world's 20 most polluted cities are in China and a recent study in *The Lancet* suggested that air pollution caused around 1.2 million premature deaths in 2010 alone.[280] One of the most popular iPad apps in Beijing is the 'China Air Quality Index', and public outcry scaled new heights in January 2013 when, for several days, the concentration of fine particles in the capital's air peaked at 886 µg/m3, almost 40 times the World Health Organisation limit for acceptable daily exposure. By contrast, levels in central London average around 13.5 µg/m3.[281] Another study, published in July 2013 in the Proceedings of the US National Academy of Sciences, revealed that people in southern China have been living on average five years longer than their northern counterparts because of the health effects of pollution.[282]

An ambitious plan to cut pollution and improve air quality in the north of China by 2017 has now been put in place, backed by 1.7 trillion RMB (US $289 billion) of state investment.[283] But air pollution is only one of a host of environmental problems that the country is confronting, and which are set to worsen in the decades ahead. In a frank interview in 2005, Pan Yue, now China's vice minister for environmental protection, outlined the threat that environmental constraints pose to China's model of growth: *"This miracle will end soon because the environment can no longer keep pace....Acid rain is falling on one–third of our territory; half of the water in China's seven largest rivers is completely useless; a quarter of our citizens lack access to clean drinking water; a third of the urban population is breathing polluted air."*[284] Other equally serious issues China faces include desertification caused by overuse of land, soil contamination with heavy metals and habitat and biodiversity loss.

Since 2006, China has been the world's largest emitter of greenhouse gasses[285] (though it only ranks 61st in the world by per capita emissions.)[286] China is at the sharp end of many of the impacts of a changing climate. The 12th Five Year Plan avoided imposing firm limits on total carbon emissions, but included some ambitious goals for 2015 in relation to energy efficiency: to reduce energy consumption per unit of GDP by 16 per cent; and emissions per unit of GDP by 17 per cent. It also set a target to increase the proportion of non–fossil fuels in the energy mix from 8.3 per cent to 11.4 per cent by 2015. Early signs are that these goals will be met: recent figures from the NDRC show that in 2012, China's carbon intensity fell by 5 per cent (outperforming its 1.5 per cent target) and its energy intensity fell by 3.6 per cent.[287]

In part, this is being achieved through an effort to broaden the energy mix. China is pouring resources into clean energy, and now ranks first in the world in terms of its generation capacity for renewable electricity. In 2012, it invested US $65.1 billion in renewables; a 20 per cent increase on the year before.[288] Of this amount, US $31.2 billion went into solar energy (around 25 per cent of that year's entire global investment) and the Chinese government recently announced plans to install a further 35 GW of solar power capacity by 2015.[289] Installed wind power capacity has also risen fast, reaching 63 GW in 2012, and is expected to reach 100 GW by 2015.[290] Investment in new nuclear power is also increasing, with 17 commercial reactors now operating, and 28 more under construction, capable of producing a total of 58 GW of power by 2020.[291]

THE SUN GOES OUT ON SUNTECH

Just before the financial crisis in 2008, Shi Zhenrong, founder of solar panel manufacturer Suntech Power said *"We believe that in ten years, Suntech will be an energy giant like BP or Shell today."*[292] His enthusiasm seemed well placed and by 2011, Suntech had become the world's largest solar panel manufacturer by sales.[293] Fast forward just two years and its dreams have been dashed by bankruptcy.[294]

Suntech's rise, from a start–up company founded in 2001 by a returnee with a PhD from Australia, to the world's number one manufacturer of solar panels was largely achieved with government support in the form of tax subsidies and access to cheap finance. At the end of 2011, Suntech owed Chinese banks $2.3 billion,[295] one of many solar companies which in total received $32.6 billion from Chinese banks in 2010.[296]

Consequently, by 2011, China had a solar production capacity of 50GW, compared to a total world installed solar capacity of 27GW.[297] This oversupply caused a massive fall in the price of solar panels, of almost 50 per cent in 2011 alone.[298] Add to this weak demand resulting from many European countries cutting their solar feed in tariffs and the US placing barriers on Chinese solar panel imports, and Suntech's losses quickly started to mount.[299]

The problems facing Suntech are not limited to solar panels. In 2011, the production capacity of Chinese wind turbine manufacturers almost equalled the total global installed wind capacity.[300] Suntech's bankruptcy shows that the central government is starting to deal with issues of overcapacity, but local governments are reluctant to cease support to unprofitable companies because of the local jobs they create. Bigger changes are anticipated on the demand side, with central government announcing plans in 2013 to quadruple domestic solar generation capacity by 2015.[301]

Despite impressive progress, the challenges involved in moving China's economy onto a cleaner, low–carbon and more sustainable path remain substantial.[302] Demand for coal is expected to increase by 50–60 per cent over the next two decades before it plateaus, and a recent report commissioned by Greenpeace included China prominently in a list of projects that will act as 'carbon bombs', citing plans by five of its north–western provinces to increase coal production, generating a further 1.4 billion tonnes of emissions a year.[303]

The incoming leadership, which is well aware of China's environmental problems, quickly declared 'ecological progress' to be one of its priorities. In his debut press conference as premier, Li Keqiang pledged to *"upgrade China's development model to enable people to enjoy clean air, safe drinking water and food."*[304] It is expected that pollution control and other environmental measures will receive greater priority in the next Five Year Plan, which will take effect from 2016. Ahead of that, there is speculation that China will sign up to a binding target for reducing carbon emissions, which could ease the current impasse in international climate negotiations.[305] Already, China is piloting emissions trading schemes in seven cities and provinces (Beijing, Shanghai, Tianjin, Chongqing, Guangdong, Hubei and Shenzhen), which are intended to build towards a national scheme after 2015.[306]

In an attempt to address China's environmental problems, the former leadership attempted to measure China's 'Green GDP', or GDP minus the costs of environmental damage. In 2006, the National Bureau of Statistics released the figures for 2004, which showed that environmental damage had cost China 3 per cent of its GDP that year. While this is a huge

loss, at around US $58 billion, some have even called it an underestimate. However, the project was killed off by political opposition in its second year, and efforts to revive it have so far been unsuccessful.[307]

Other schemes to boost sustainability include China's plans to build low–carbon and smart cities. Thirteen jurisdictions have now been designated as low–carbon economy pilot zones, able to experiment with different policies and approaches at a local level.[308] And in August 2013, the government launched a smart city programme with nine pilot cities.[309]

This fast–changing policy context means that low–carbon, sustainable innovation can only grow in importance over the next decade, creating particular trade and collaborative research opportunities for the UK and other countries. Current patterns of US–China trade in clean energy technologies illustrate this point: in 2011, this market was worth a total of US$ 8.5 billion, with US exports to China exceeding imports by US$ 1.63 billion.[310]

Social innovation

Local air quality and environmental pollution has been one of the causes of more visible public unrest over the past five years that has alarmed China's leadership. During the period of the 11th Five Year Plan, the Ministry of Environmental Protection received 300,000 petitions on environmental issues. Such protests increasingly spill onto the streets: in May 2013, Kunming became the site for environmental demonstrations against the nearby construction of an oil and chemical refinery;[311] and in July 2013, a rare protest against nuclear power took place in Jiangmen, Guangdong province, prompting the local government to agree to halt plans to build a uranium–processing facility.[312]

These are local manifestations of a broader and significant trend: towards a more visible and proactive civil society in China, demanding a greater say in how policies are made and institutions are run.[313] Speaking recently to the *Financial Times,* Gao Bingzhing, director of the Centre for Civil Society Studies at Peking University, explained that *"Civil society has already become very firm and deep–rooted in China…The transformation of civil society into political demands is a general phenomenon. China is no exception."*[314]

Estimates suggest there are over 620,000 NGOs in China today,[315] a number that grew rapidly following the devastating 2008 Sichuan earthquake. In an article for the *Stanford Social Innovation Review,* Meng Zhao identifies 2011 as a turning point in the development of the non–profit sector, with the end of the complex 'dual administration' system which restricted the registration of new non–profit entities in a landscape dominated by GONGOs (government–owned NGOs).[316] Yet the government's instinctive distrust of civil society has created a uniquely Chinese model whereby the government tries to create and manage social innovation.[317]

A more vibrant civil society, allied to growing public support for social and environmental goals, has promoted a lively debate about what social innovation (a concept now of interest worldwide) means in the Chinese context.[318] In one sense, China has an extraordinary story of social progress to tell. Its rapid growth has lifted well over 600 million people out over poverty since 1981.[319] But inequality has risen dramatically alongside this, and while official Chinese statistics show a Gini coefficient on a par with the US, other estimates suggest the gap is greater.[320] A fresh round of social reforms were announced in February 2013, yet analysts suggest that there may be roadblocks to implementing these.[321]

The latest policy guidance for indigenous innovation talks of stepping up efforts to 'improve innovation capabilities in key social fields' – with an emphasis on education

and digital technology, healthcare systems and technologies, public safety and disaster management and the 'modern cultural industry system', which covers industries ranging from publishing and printing to online games and animation.[322]

While the concept of 'social innovation' is far from widespread in China, it does have its champions.[323] Beijing University's Professor Yu Keping has collected extensive case studies of 'innovations and excellence in local government'.[324] There are now annual awards for best practice, with examples this year including Minxin Net in Liaoning Province, an online platform for the registration of public complaints and NPI, an incubator in Shanghai's Pudong district, which markets itself as a social innovation park.[325]

Various approaches to social innovation are being experimented with across civil society, including crowdfunding,[326] microcredit and time banks.[327] Yet despite these and other pioneering projects, there is still a long way to go before China develops its own distinctive and thriving culture of social innovation. Deng Guosheng, Director of the Center for Innovation and Social Responsibility at Tsinghua University, suggests that proper funding and a supportive policy environment are still lacking.[328]

Just like technological innovation, social innovations can be incremental or radical.[329] As in other domains of innovation, China is increasingly adept at copying and absorbing models of social innovation from elsewhere and making incremental improvements to them to suit the Chinese context, but has not yet pioneered many of its own. But this will change rapidly in the next ten years as social innovation takes off in China and new models start to appear.

All of these shifts create exciting opportunities for the UK, which has deep strengths in design, branding, advertising and in understanding consumers; has long been at the forefront of environmental technologies and regulation; and has pioneered emerging models and practices of social innovation. With careful planning and positioning, the UK could become a crucial ally and business partner for China on its journey to a rebalanced, more sustainable and socially cohesive economy.

7: INNOVATION DIPLOMACY AND COLLABORATION

> *"The development of science and technology requires extensive international cooperation. Science and technology have no nationality!"*
>
> **President Xi Jinping, 2012**[330]

Until recently, Sunnylands, a 200–acre luxury estate in Rancho Mirage, California, was best known as the venue for Frank Sinatra's wedding to Barbara Marx in 1976; the fourth, last and longest of his marriages.[331] But in June 2013, it provided the backdrop for the start of another new relationship: the first summit between Barack Obama and Xi Jinping.

Topics on the eight–hour agenda included North Korea, climate change and cyber security, and although discussions were somewhat overshadowed by breaking revelations of the USA's own programme of state–sponsored cyber espionage,[332] the summit was regarded as a success. In the press conference that followed, President Xi observed that *"China and the United States must find a new path – one that is different from the inevitable confrontation and conflict between the major countries of the past."*[333] Harvard political scientist Joseph Nye described it as *"the most important meeting between an American president and a Chinese leader in 40 years, since Nixon and Mao."*[334]

For seasoned observers, one striking aspect of the lead–up to the Sunnylands summit was the repeated reference by Chinese officials to a 'new type of great–power relationship' between China and the United States. This idea – xinxing daguo guanxi – was first elaborated by Xi in a speech he gave in Washington DC in February 2012, when he was still vice–president.[335] Xi explained then that such a relationship would be characterised by *"mutual understanding and strategic trust, respecting each other's core interests, mutually beneficial cooperation and enhancing cooperation and coordination in international affairs and on global issues."*[336] As a concept, the 'new type of great power relationship' remains vague but signals a heightened level of confidence and ambition.

In line with Xi's broader narrative of 'the great renaissance,', it suggests that the advice of the late Deng Xiaoping that China should *"hide its brilliance and bide its time"* has been discarded in favour of a more assertive relationship with other nations. It is a realignment that is far from complete: one recent and influential analysis insists China is still a 'partial' power.[337] *"China is a global actor without (yet) being a true global power"*, argues David Shambaugh. *"It remains a long way from becoming a global superpower like the United States (which has comprehensive power and global influence across economic, cultural, diplomatic, security, governance, and other realms)."*[338]

But what do these broader developments in China's foreign policy mean for its approach to collaboration in science, technology and innovation? While science and technology may have 'no nationality', for governments seeking to secure its future contribution to economic growth and competitiveness, national perspectives are vital. US–China is set to remain a dominant geopolitical axis, but around the world countries are seeking to understand what

a more strategic relationship with China in science and innovation would entail. A shift is underway from established agendas of 'science diplomacy'[339] – focused on promoting academic research collaborations – to the more expansive and sometimes treacherous terrain of 'innovation diplomacy', in which collaborative opportunities and risks need to be assessed across every link in the innovation value chain.

While other countries recalibrate their approach, China's approach to international collaboration is increasingly strategic. Since China's 'opening up' in 1978, foreign policy has long been used to advance economic development, with what David Shambaugh describes as *"overriding emphasis…placed on those nations that could provide China with advanced technology, FDI, expertise, and export markets."* Other powers, argues Shambaugh *"do not devote diplomatic resources in pursuit of economic ends anywhere near the extent that China does."* Similarly, Adam Segal from the US Council on Foreign Relations notes that *"One of China's great strengths has been a laser–like focus on shaping foreign interactions to serve national innovation goals."*[340] This strategic approach to collaboration is an important feature of China's absorptive state.

In this chapter, we look in more detail at China's approach, and how this is shaping the spread and intensity of its global research and innovation relationships. Against this backdrop, we draw on the latest bibliometric data for an in–depth assessment of the health of China–UK relations in research. We present new data which reveals that the UK has moved ahead of Japan to become the second most popular 'partner of choice' for Chinese researchers (with only the US producing more co–authored papers). Finally, we draw comparisons with the approaches of the US, Australia, Germany and the European Union to collaboration with China, and ask is there anything the UK can learn from these other national strategies?

China's approach to international collaboration in research and innovation

In August 2012, more than 2,000 astronomers from 80 countries gathered in Beijing for the 28th General Assembly of the International Astronomical Union (IAU). It was the largest meeting in the IAU's history, and its opening speaker was none other than Xi Jinping.[341] After welcoming the delegates, Xi set out five ingredients of successful science and technology, the last of which was international cooperation. As he explained: *"Nowadays the challenges for science and technology are more and more globalised…and these common problems require scientific exchanges and cooperation in various forms."*[342]

This philosophy has shaped China's approach to science and technology collaboration for more than 30 years, with impressive results. An ever–intensifying web of international connections has spread across every aspect of China's innovation system – from joint academic research to technology transfer and licensing, FDI, mergers and acquisitions. As a result, the Chinese system is densely connected to sources of expertise elsewhere (in science, but also design, management, branding and core technologies). This has been a crucial factor in the rise of China's absorptive state. One thing that marks out China's innovation pathway from that of Japan or South Korea is its willingness, where necessary 'to buy expertise off the shelf'.[343] Time and again, we see examples of highly targeted collaborations in research and innovation.[344]

By the end of 2010, China had established formal S&T relations with 152 countries and regions and signed 104 cooperation agreements. It also had 141 S&T diplomats working across 46 countries.[345] Denis Simon describes five shifts in China's approach to international cooperation since the publication of the 2006 *Medium and Long–term National Plan for Science and Technology Developmen*t (MLP):

- From general international S&T cooperation to proactive, targeted cooperation focused on the needs and mission of the MLP;
- From project–based collaboration to 'the integration of projects, talent and R&D base's';
- From an orientation to technology imports to a combined process of 'inviting in' and 'going abroad';
- From cooperation driven by government to cooperation driven by multiple players;
- From bottom–up to top–down project identification and approval in line with the requirements of the MLP.[346]

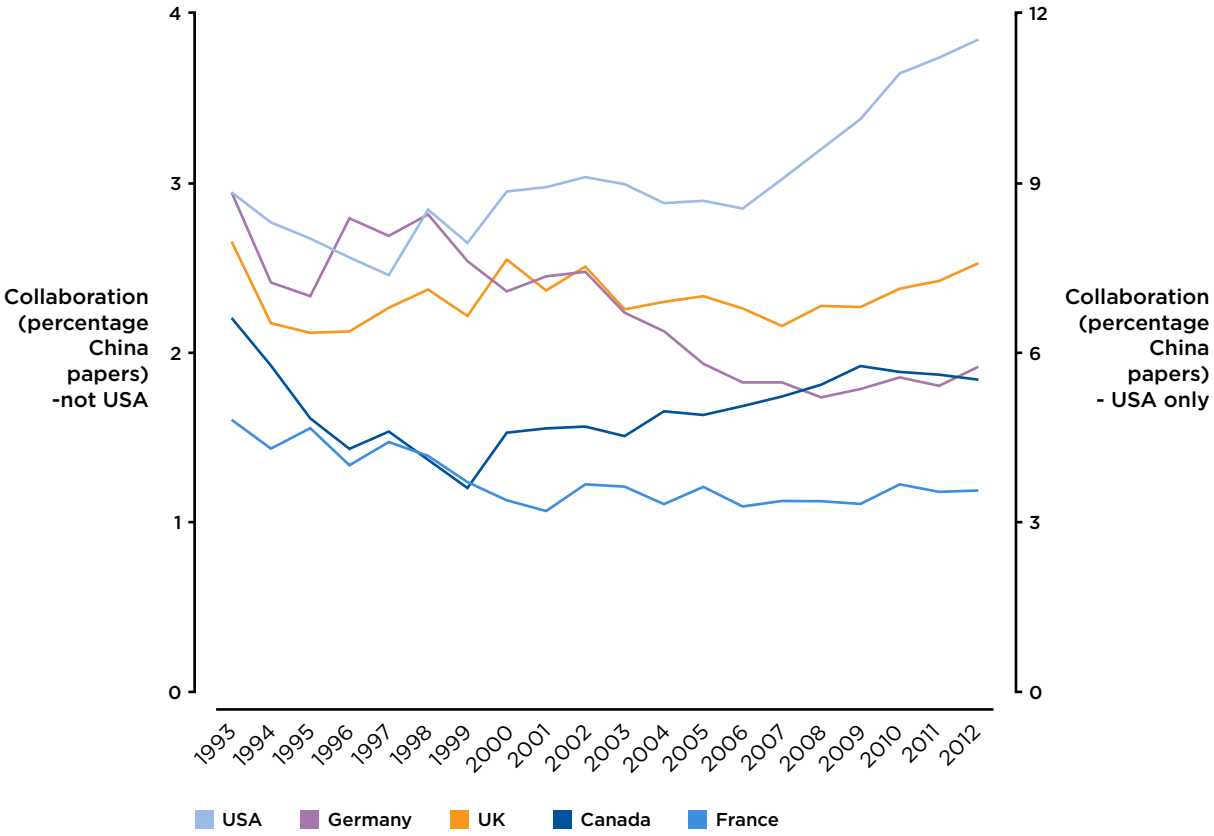
These shifts have occurred at a time when international cooperation in science and innovation has never been more important. The Royal Society's *Knowledge, Networks and Nations* report maps this increasingly interconnected and multipolar scientific world, in which over 35 per cent of articles published in international journals involve collaborations across borders, up from 25 per cent in the mid–1990s.[347] In a recent *Nature* commentary, Jonathan Adams argued that we are entering a *"fourth age of research, driven by international collaboration between elite research groups."* Based on an analysis of 25 million papers published between 1981 and 2012, Adams demonstrates that the citation impact of collaborative papers is consistently higher than those that are entirely 'home–grown'. As a result, *"institutions that do not form international collaborations risk progressive disenfranchisement, and countries that do not nurture their talent will lose out entirely."*[348]

Over this period, the dramatic growth in China's research output has been driven primarily by increased domestic activity. Papers on which there are only Chinese authors have consistently made up about three–quarters of China's total output, with around a quarter having co–authors from one or more countries. This is a very different pattern from that of G7 countries where most of the growth in the last 20 years has been through international collaboration. For example, the number of UK papers with authors only from the UK fell below half of the country's total national research output in 2010.

But as China continues to expand its research volume so it has increased its potential to collaborate. In line with the shifts described by Denis Simon, it is also starting to become more selective about where it sources its knowledge and focusing on partners who can make a significant collaborative contribution.

As the world's largest and best–performing research power, the US has long been a favoured partner. US collaboration with China is much higher than for other nations, as displayed in Figure 11 (p.64). Over the past decade, US–China collaboration has increased relative to total China output: that is to say, it now accounts for a bigger share of a bigger pot. In 2011, more than 10 per cent of China's papers had a US co–author. The UK has also slightly increased its collaborative share of China's output, to around 2.5 per cent, and has recently moved ahead of Japan as China's second most popular research partner. Other leading European nations (Germany and France) have fallen slightly in their collaborative share to below 2 per cent. Canada's share is now rising after a marked dip in 1990s, but that dip was in share and not in absolute volume.

Figure 11. **China's research co-authorship with leading Western research economies**[349]



The data suggest the UK is in a favourable position compared to other nations seeking links into China. Yet it is important to reflect on how long this can last, as maintaining the UK's share of China's activity is absorbing an increasing part of the UK's limited collaborative capacity (Figure 12).

Figure 12. **China–UK collaboration as a share of each country's total output**[350]

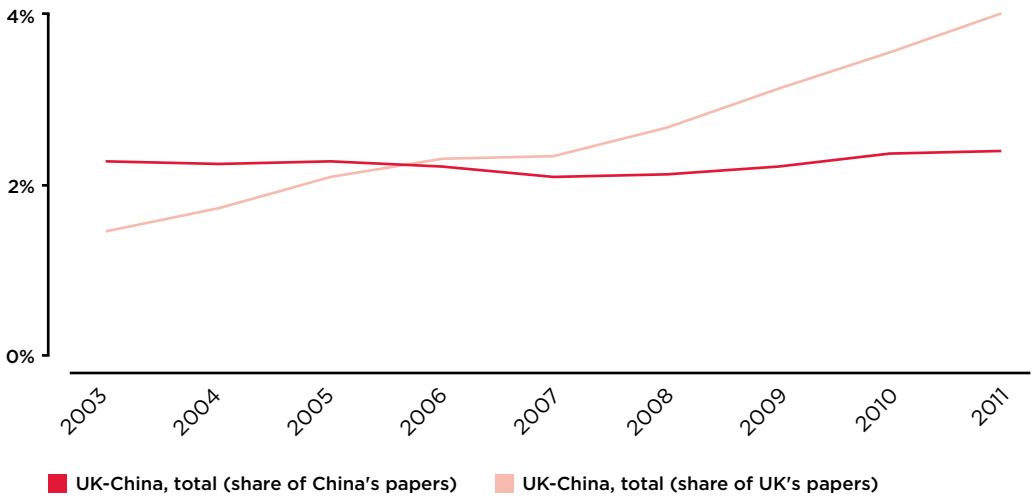
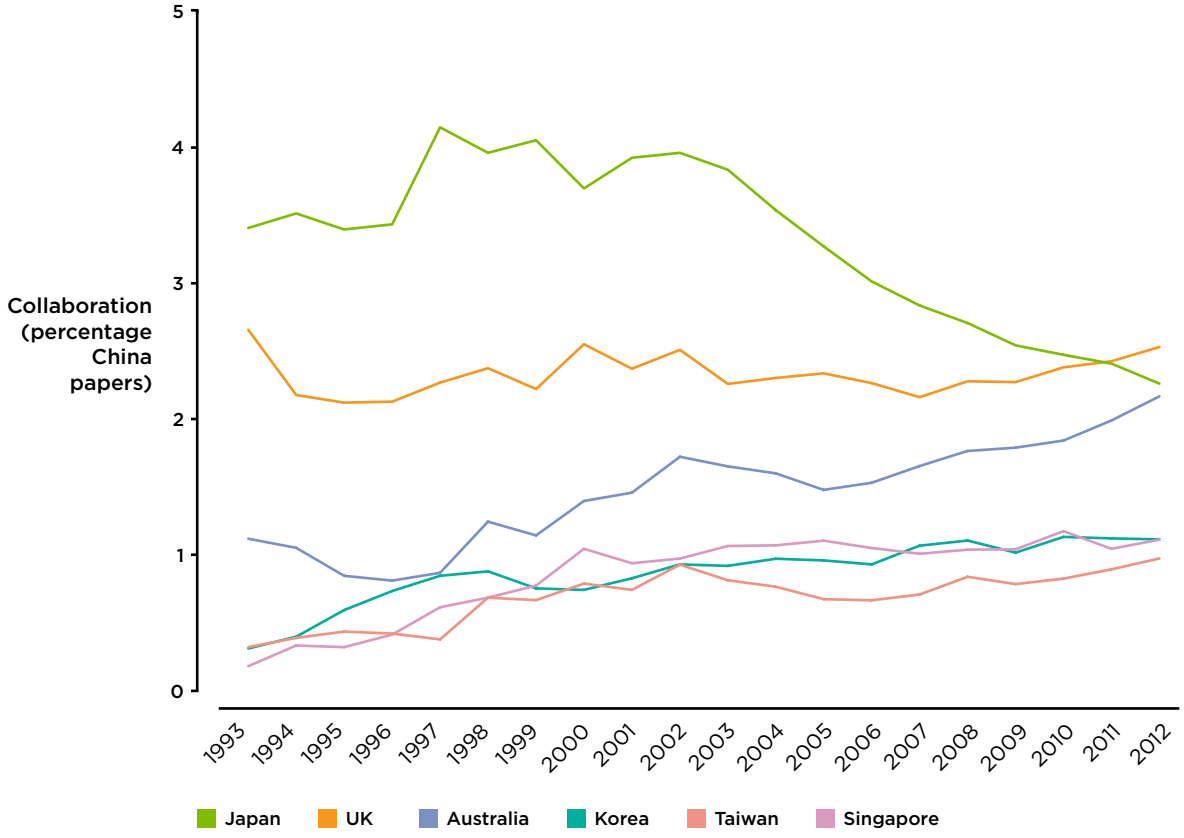


Figure 13. **China's research co-authorship with Asia–Pacific research economies** (UK included for reference)[351]



China's collaboration with other Asia–Pacific nations is shown in Figure 13. Japan's collaborative share was ahead of the UK but has dipped sharply. By contrast, Australia's collaboration has doubled as a share of China output over 20 years and is now ahead of Germany, with a share approaching that of the UK. Collaboration with the smaller research economies of South Korea, Singapore and Taiwan is growing but has flattened slightly at around 1 per cent each, possibly limited by the size and therefore the collaborative capacity of those nations.

Competing in the 'global race': the UK's approach to collaboration

In his speech to the 2012 Conservative Party conference, Prime Minister David Cameron offered what he felt were tough truths to the British people: *"We are in a global race today. And that means an hour of reckoning for countries like ours. Sink or swim. Do or decline."* He went on to contrast his participation in *"European Council meetings where we talk endlessly about Greece...while on the other side of the world, China is moving so fast it's creating a new economy the size of Greece every three months."*[352] This idea of the 'global race' is now a recurring motif of UK government announcements on growth, trade and globalisation, and influences the way in which the opportunities and challenges of collaboration with China are understood.

The main framework for UK policy in this area is the December 2011 *Innovation and Research Strategy for Growth.*[353] It acknowledges that 'the UK's position as a global leader in innovation and research depends on an internationally mobile and highly collaborative research workforce' and it sets out five pillars of international engagement:

- Promoting the UK's research and high–technology sectors overseas;
- Supporting UK businesses' and researchers' access to international markets and collaboration;
- Ensuring the UK continues to attract globally mobile capital, technology and highly–skilled people;
- Strengthening our engagement with initiatives within the European Single Market; and
- Building strategic links with high–growth economies.

Unsurprisingly, China is highlighted as one of the high–growth economies with which the UK wants to increase its volume of collaborative activity. On China specifically, the strategy notes the broadening range of science and innovation relationships with China, but says *"urgent action is needed to achieve more strategic engagement, aiming for a step change in our engagement with China's science and innovation systems by 2020."* It lists four specific initiatives in support of this objective:

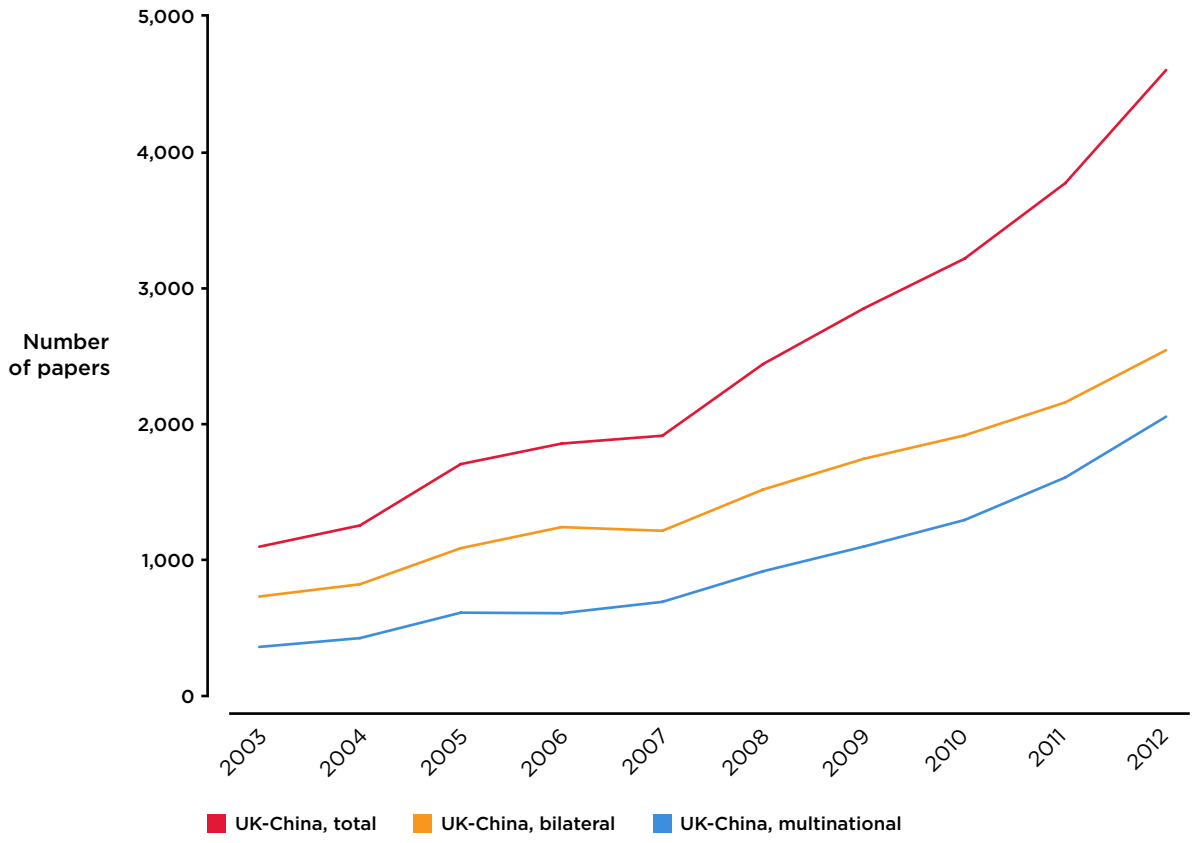
- Encouraging the UK's new Catapult Centres to build relationships with the Chinese 'TORCH' innovation centres for mutual benefit, as they become established;
- Expanding UKTI's Enabling Innovation UK–China Partnership in ICT;
- Using the new Beijing representative of the Intellectual Property Office to help UK businesses gain the knowledge they need to operate in the Chinese IP environment and to press for further improvements;
- Engaging with the Chinese Ministry of Science and Technology in a jointly funded pilot initiative to support bilateral research projects in key areas of mutual interest.

Assessing the health of the current China–UK relationship in research and innovation is challenging given the limited range of available and comparable data. Later in this chapter we assess factors such as trade and institutional presence, but first we examine the health of research collaboration between China and the UK.

China–UK collaborative research

China and the UK have a strong research relationship, supported by a network of bottom-up, researcher-led collaborations and a growing number of joint funding initiatives. These have contributed, in 2012, to the UK becoming China's second largest research collaborator in terms of co-authored papers. The volume of collaborative output has increased four-fold (x 4.2) over the period 2003 to 2012 from around 1,000 papers per year to over 4,500 papers in the last year.[354]

Figure 14. **China–UK collaboration showing split by bilateral and multinational papers**[355]



While international teams account for a considerable share of these papers, more than half of the China–UK joint papers of the last ten years are bilateral: that is, they had only UK and Chinese co-authors. In 2012, about 2,000 (around 40 per cent) of the China–UK papers published in that year had additional co-authors from other countries (Figure 14).

UK universities which collaborate the most with China, and Chinese universities which collaborate the most with the UK can be seen in Table 14. UK collaboration in China is spread less intensively across more institutions, while in the UK it is relatively concentrated. There are, in fact, more than 50 Chinese universities that have at least 100 China–UK co-authorships in the last ten years and a further 50 with over 50 collaborative papers.

Table 14. **Institutions that are frequent co-authors on China–UK collaborative papers (2003–2012) and the average normalised citation impact of the co-authored papers**[356]

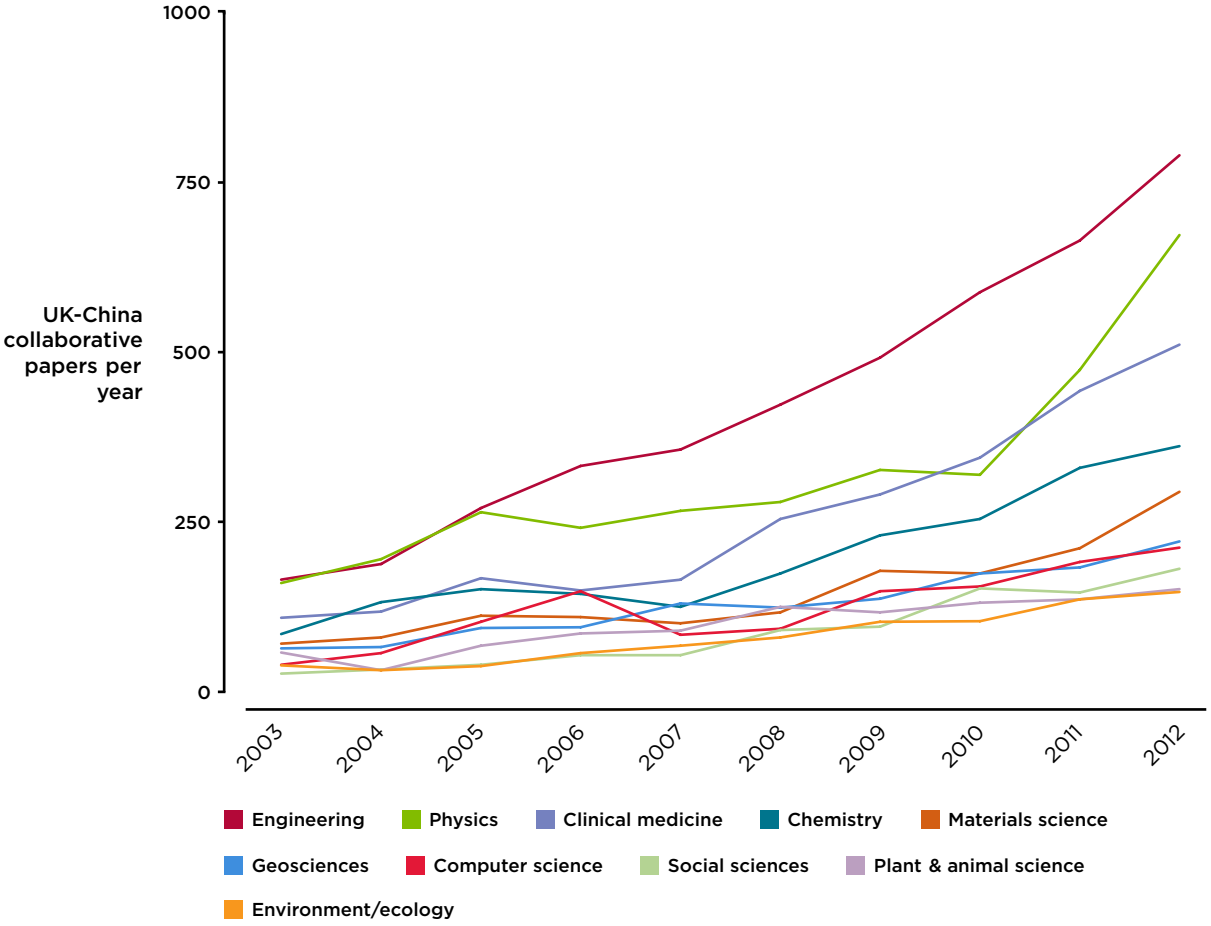
UK institution	Papers with China	Average citation impact	China institution	Papers with UK	Average citation impact
Imperial College London	2,041	2.36	**Peking University**	1,176	2.28
University of Manchester	1,942	2.06	**Chinese Acad Sciences**	1,004	2.04
University of Oxford	1,687	3.48	**Tsinghua University**	929	2.25
University of Birmingham	1,556	2.58	**CAS Univ of Sci and Technol**	903	3.08
University of Cambridge	1,521	3.53	**Zhejiang University**	669	1.54
University College London	1,370	2.93	**Shanghai Jiao Tong Univ**	594	1.76
University of Liverpool	1,079	2.64	**Fudan University**	578	1.44
University of Edinburgh	1,045	3.90	**CAS Graduate University**	539	1.26
STFC R'ford Appleton Lab	1,002	4.45	**Sun Yat-sen University**	509	2.72
University of Bristol	994	2.30	**CAS Inst High Energy Phys**	493	2.86
Brunel University	965	3.00	**Nanjing University**	434	2.79
Univ of Southampton	919	3.11	**Xi'an Jiaotong University**	409	0.92
Queen Mary Univ London	802	2.22	**Harbin Inst Technology**	406	2.05
University of Sheffield	796	3.97	**Shandong University**	389	2.81
King's College London	718	1.90	**CAS Nat'l Astronom Obs**	305	1.62

Major fields of research collaboration

Research collaboration between the UK and China is not evenly spread across fields. Figure 15 shows the spread by ESI field, and the trajectory of growth in collaboration over the last ten years. As might be anticipated from the wider balance of China's research efforts, Engineering (4,272 total China–UK papers for 2002–2012), Physics (3,204), Clinical Medicine (2,558), Chemistry (1,995) and Materials Science (1,458) are the categories with by far the largest number of collaborative papers. No other field exceeds 250 papers per year, but Geosciences and Computer Science are on track to do so in 2013.

The fields with the most rapidly growing China–UK collaboration are generally in the biomedical sciences: Molecular Biology and Genetics, Immunology, Pharmacology and Toxicology and Clinical Medicine all have above average growth. In addition, China–UK co-authorship in Economics and Business and Social Sciences has also grown four-fold in the period.

Figure 15. **Growth of China–UK collaboration by ESI field**[357]



Another perspective on indexing the relative intensity of China–UK research co–authorship is to calculate the percentage of the total output in each field nationally that is accounted for by papers that are the result of international collaborations. This is done in Table 15 for a recent five–year window (2007–2011) where we can readily compare collaborative papers with the national background.

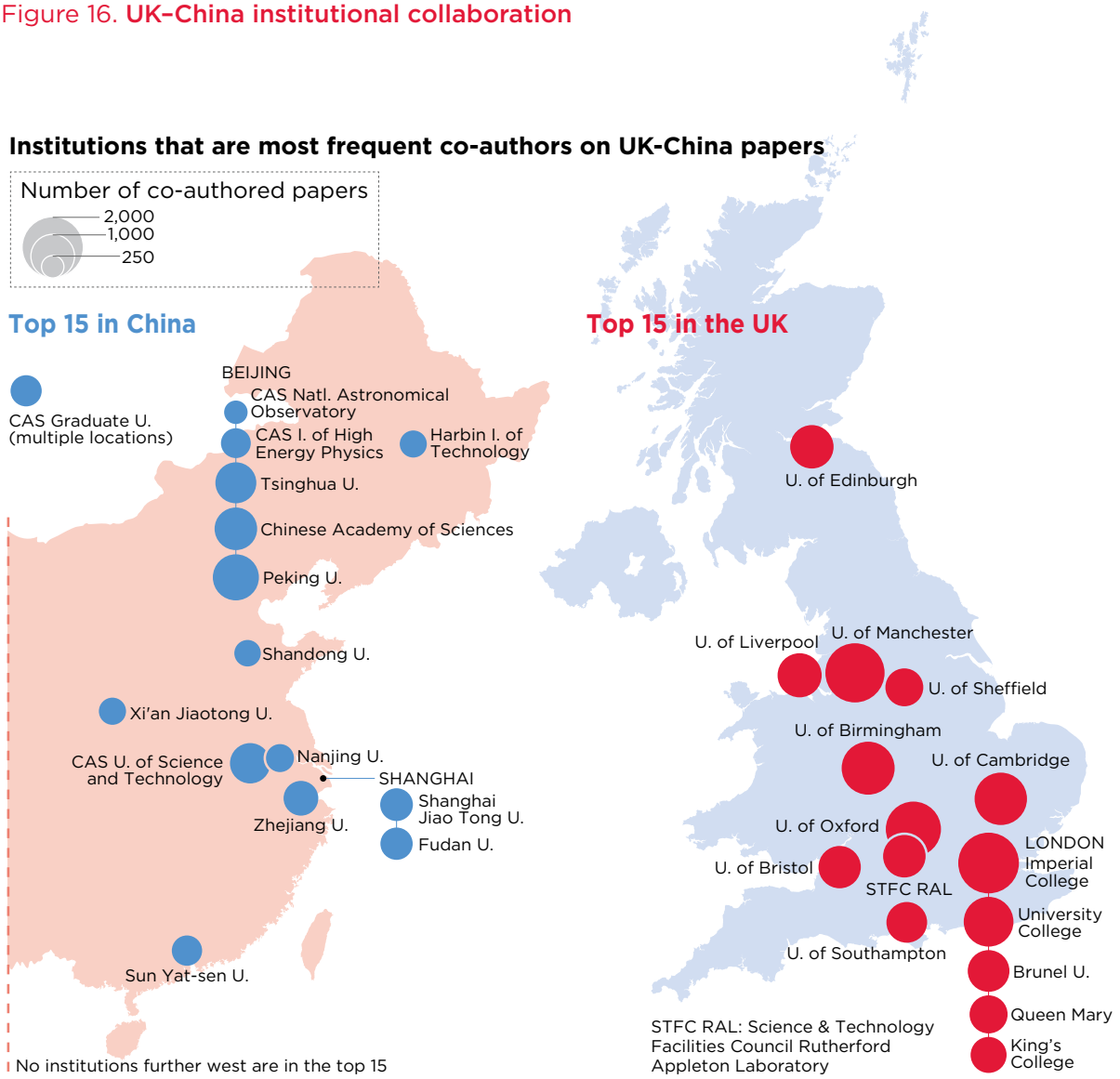
Table 15. **China–UK co–authorship for 2007–2011 and as a percentage of each country's total output in each ESI journal category**[358]

ESI field	% of national research		
	Joint papers	China	UK
Agricultural Sciences	206	2.02	4.00
Biology and Biochemistry	510	1.96	2.14
Chemistry	1117	0.84	3.48
Clinical Medicine	1500	2.54	1.38
Computer Science	676	4.37	8.08
Economics and Business	297	6.76	2.19
Engineering	2524	3.50	8.36
Environment/Ecology	496	3.06	3.77
Geosciences	753	3.73	4.57
Immunology	160	4.01	2.57
Materials Science	786	1.20	6.71
Mathematics	330	1.30	3.52
Microbiology	278	3.56	3.67
Molecular Biology and Genetics	471	3.76	2.93
Neuroscience and Behaviour	286	3.28	1.88
Pharmacology and Toxicology	225	2.54	4.08
Physics	1668	0.25	0.68
Plant and Animal Science	604	7.38	8.18
Psychiatry/Psychology	233	21.8	3.33
Social Sciences general	544	3.48	0.64
Space Science	437	10.16	4.90

China–UK collaboration in Materials Science and in Engineering already takes up an above average percentage of UK capacity, accounting respectively for 6.7 per cent and 8.4 per cent of UK papers against around 2.5 per cent overall. Similarly, Plant and Animal Sciences are an existing area of relatively intense collaboration for both countries (7–8 per cent for each) whereas Physics co–authorship only accounts for a relatively small percentage of each country's papers.

From China's perspective, the Materials Science collaboration is a small part (1.2 per cent) of total national activity. This means that even though the UK appears to be strongly engaged, it is in fact only working with a relatively small part of China's total capacity in this area. At the same time, a substantial part of the UK's capacity is already taken up. The same dynamic applies in Chemistry, and reflects a potential obstacle to widening collaborative activity in certain strategic areas.

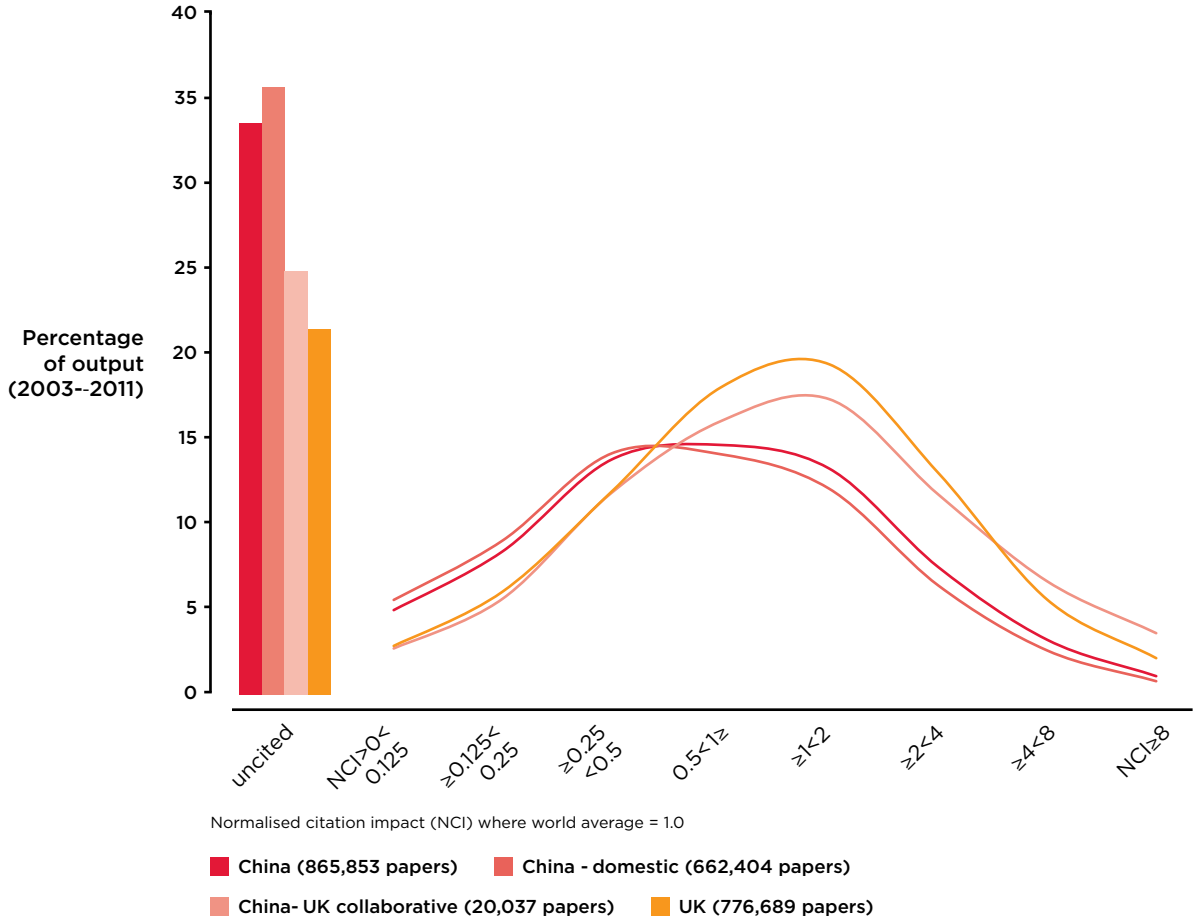
Figure 16. **UK–China institutional collaboration**



Understanding the impact of China–UK research collaboration

One way to quantify the impact of research is to look at the number of times a set of papers is cited by other papers. The most accessible metric for judging impact of collaboration is to look at an average citation impact. While this gives a helpful comparative indicator, it can sometimes be misleading. It is always the case that a small proportion of papers will attract many citations, while a large proportion will attract few or no citations (for example, even ten years after publication, about 10 per cent of the UK's papers remain uncited). To overcome the problem of interpretation that this creates, and to get insights into the spread of performance, Thomson Reuters developed Impact Profiles™ which reveal the spread of weak and excellent performance around the world average (Normalised Citation Impact (NCI) = 1.0) and highlight the balance of uncited and cited papers.[359]

Figure 17. **Impact Profile™ for papers published by China, the UK and co-authored papers between the two countries (2003–2011) and indexed in journals on Thomson Reuters' *Web of Science*[360]**



Accounting for variable population and output rates, these charts show the difference between the impact of UK research and that of China. This broadly reflects what we might expect: the Chinese national curve exhibits relatively more uncited papers (as shown by the column to the left) and low-cited papers (with the left side of the curve above that of the UK). The Chinese national curve shows that there is a 'hump' of research at or below world average, while the UK research curve peaks above world average. But the curve to the right hand side reveals that China is also producing a growing body of excellent research that is far above world average. In fact the impact of 5 per cent of its ten-year output (43,000 papers) is more than four times world average. A substantial part of these papers have purely domestic authorship, so this higher impact is not attributable solely to international collaboration.

When we turn our attention to the curve representing China–UK collaborative research, the China–UK collaborative data are slightly better than the UK curve overall, and much better than the China curve. The collaborative research output features more uncited papers than the UK (24 per cent vs 21 per cent) but similar percentages of low-cited papers. While there are relatively fewer papers in the range 0.5 to four times world average than the UK's national output, there are relatively more papers in the high-impact categories (above four times world average).

From this data, we can infer that China gains considerably from joint research across the board, and that the UK gains primarily at the high impact end. A critical point is that the UK gains access to a large, growing and rapidly–improving body of research which can support and influence the rest of its portfolio. Collaboration brings insights not only into what the best Chinese researchers have done, but what they are planning to do next.

HIGHLIGHTS OF CHINA–UK JOINT RESEARCH SINCE 2007

1. The Innovation China–UK programme, set up in 2007 with £4.5 million in funding from HEFCE, BIS and MOST, supported 72 joint projects and led to £1.9 million in match funding from Chinese institutions, 25 joint research papers and 14 patents.

2. In 2008 and 2009, RCUK conducted two energy calls in partnership with MoST covering Hydrogen and Fuel Cells and Cleaner Fossil Fuels (£6.6 million and £4.5 million from RCUK).

3. In 2012, RCUK and MoST launched the China–UK Programme in Global Priorities, which aims to facilitate bilateral cooperation between research groups working on healthy ageing populations, energy and food security. RCUK and MoST each invested £1 million and four projects were funded.

4. A series of joint calls have been launched since 2008 with the National Natural Science of China (NSFC). These include Nanospintronics, Carbon Capture and Storage and Smart Grids and Electric Vehicles, with a total of over £8.65 million from RCUK plus matched funding from the NSFC. Future calls on sustainable materials for infrastructure and the next phase of the China–UK stem cells initiative are planned in 2014.

5. The Chinese Academy of Sciences (CAS) has supported the following joint activities with the UK: solar cells, solar fuels and fuel cells (RCUK invested £2.5 million with matched funding from CAS); Synthetic Biology China Partnering Award (BBSRC and EPSRC committed £25,000 per award matched by CAS).

6. There are ongoing efforts to strengthen links between CAS institutes and centres in the UK. For example, CAS has recently funded a new centre of excellence to connect the John Innes Centre (JIC) with CAS institutes working on plant and microbial sciences.

7. The extensive China–UK engagement on the climate change agenda includes memoranda of understanding (MOUs) between several UK government departments and their Chinese counterparts; a joint Technology Strategy Board and EPSRC program with MoST to support innovation in sustainable manufacturing; and over £24 million in funding from RCUK for joint energy projects with Chinese research funders.

Benchmarking national strategies for collaboration

Data on co–authored research papers highlights one dimension of China's collaborative links with the UK and other countries. But there are many other aspects of a broader strategy for innovation collaboration that cannot be captured through bibliometric analysis. For instance, there is much to be gained from collaboration between China and the UK on innovation in services and creative industries. For example, Nesta is currently collaborating on a project with Douban, one of China's biggest online cultural communities, to explore market opportunities for UK creative content in China.

As part of the research for this report, we reviewed the available literature on collaboration strategies, and interviewed a targeted selection of research policymakers, funders and programme managers in the UK, US, Australia and Germany.

Below we cluster our findings under five headings which reflect important aspects of any country's approach to collaboration with China on research and innovation:

- Joint research.
- Strategic frameworks.
- Trade and business links.
- Influence on Chinese policy.
- Student flows.

This is a complex area, and what we present below is just a starting point, which would benefit from more systematic quantitative and qualitative analysis.

Joint research

- In 2012, 11.5 per cent of China's papers had a US co–author, making the US China's main research collaborator. Research links between the two countries continue to steadily increase.
- As described above, the UK has recently passed Japan to become China's second largest research collaborator, but Australia is catching up fast and may overtake it in the next few years on extrapolation of current trends. Unlike its UK counterpart, the Australian Research Council does not have an office in China. While Australia now has a strong overarching strategy of economic collaboration with Asia, it is unclear what precise actions have led to this growth in collaboration.
- Germany lags behind other countries on this list in terms of joint published papers, However, German research funders and institutes have a strong presence on the ground in China and there are several joint Sino–German research centres. Rainer Frietsch of Fraunhofer ISI observes that: *"Germany has many representatives in China: universities, chambers of commerce, federal states, research institutes, and companies like VW, BASF and Bayer....Small bricks make a big wall."*[361]

- A China–EU S&T agreement was signed in 1998 and renewed in 2009. The volume of collaborative research has steadily increased under the EU's last three Framework Programmes, placing China third, after the US and Russia, in terms of the total number of non–EU participants.[362] Some have expressed concern that stricter eligibility criteria in the forthcoming Horizon 2020 round may reduce levels of China–EU collaboration. European Commission officials however, insist the changes will allow a substantial volume of research to take place, within clearer guidelines.[363]

Strategic frameworks

- Few countries publish a single document designed to capture their overall strategy towards engagement with China. The Australian government's white paper, 'Australia in the Asian Century,' is the closest attempt to do this. Australia, which has a smaller population than the city of Shanghai, realises that collaboration across the Asia–Pacific region is crucial to its future prosperity.[364] Tricia Berman of Australia's Department for Innovation[365] suggests that: *"Australia is now more mature in its relations with China than most. It has got past major concerns such as IPR expressed by OECD countries…Engagement, trust and an ongoing rapport are key to creating future partnerships."*[366]

- The US is in an altogether different position. Despite its strong links to China – particularly in the economic sphere – the frequency of reports and political rhetoric which are critical of aspects of Chinese policy reflect the US's desire to encourage a level playing field and protect its economic advantages. Yet behind the often–hawkish public debate, US officials work quietly and steadily to strengthen US–China collaboration. According to Oliver Chase of the American Chamber of Commerce in China, *"US officials in China spend a lot of their time telling the Chinese the difference between policy and politics in the US."*

- Germany's strategy towards China is based on manufacturing links and maintaining its export markets. According to Wolfgang Crasemann of the Federal Ministry of Economy and Technology (BMWI): *"Industry is the forerunner in our policy considerations."*[367] An example of this is the role that Germany played in opposing the EU's planned tariff on imports of Chinese solar panels, fearing that it would harm its trade relationship with China.[368]

- The UK approach is closer to that of Germany and Australia than the US. However, it can occasionally strike a more hawkish note on trade and innovation links. For example, a recent parliamentary report from the UK's Intelligence and Security Committee raised concerns about Huawei's role in the national telecoms infrastructure. However, this is unusual: in general, the UK government is vocally supportive of more inward investment from Chinese companies.[369]

- In addition to RCUK's China office, which has been operational since 2007, the UK has a growing network of Science and Innovation Network representatives and specialist IPO attaches in its Embassy and Consulates across China. UKTI and the China Britain Business Council work together to provide advice and assistance to UK companies looking to do business in China. The two countries convene a bi–annual ministerial dialogue on science and technology which has recently been complemented by an annual official–level innovation dialogue between BIS and MOST.

Trade and business links

- The EU is China's largest source of imports and China's second largest export market, after the US.[370] Within the EU, Germany is China's largest trading partner, accounting for around 46 per cent of total EU exports to China in 2012.[371] A recent briefing by the European Council on Foreign Relations argues *"At present, there is an almost perfect symbiosis between the Chinese and German economies. China needs technology and Germany needs markets."*[372]

- In 2011, China became the UK's 7th largest export market for goods. UK exports to China totalled £10.54 billion in 2012, a 13.4 per cent increase on 2011, and an increase of over 700 per cent since 2002.[373] While the UK had a trade deficit with China in goods of £21 billion in 2012, it had a trade surplus in services of £1.8 billion.[374] Trade in services is a promising area for future UK collaboration with China, particularly in health, education and finance, all areas where the UK has strengths. According to experts there are now 400 Chinese companies in the UK.

- China is Australia's largest trading partner, and Australia was China's 11th largest export destination and 6th largest origin of imports in 2012.[375] However, 70 per cent of Australia's exports to China are raw materials, such as iron ore and coal. This balance is recognised as a longer–term problem in Australia, particularly as China's gradual economic slowdown has been reducing demand for raw materials.[376]

Influence on Chinese policy

- US diplomacy and lobbying has a strong influence on Chinese innovation policy. Both the first and second amendments to China's patent law came about after pressure from the US.[377] China also dropped its overt requirements for government departments to only procure products certified as 'indigenous innovation products' after pressure from foreign governments, led by the US. The US is also the most frequent user of the WTO's dispute settlement mechanism against China.[378]

- The US–China Innovation Dialogue was launched in 2010 to discuss contentious issues related to innovation policies and promote best practices. It includes two parallel tracks: ministerial–level discussions at the policy level, and an expert group, led by Rob Atkinson, head of the Information Technology Industry Foundation, and Tsinghua University Professor Xue Lan. The dialogue has become an important component of wider US–China economic and trade relations.[379]

- The EU's collective influence on China's innovation policy is often weakened by the lack of unity among its member states. Godement and Parello–Plesner argue that China is *"happy with having 27 bilateral relationships, in which China nearly always has the upper hand."* This lack of cohesion was reflected recently when several countries in the EU area criticised the EU trade commissioner for threatening to impose tariffs on imports of Chinese solar panels, which led to the tariff being substantially reduced.

- Like the UK and the US, Germany and Australia carry out regular high–level dialogues on economic, trade and innovation policy with China. While the outcomes of US–China dialogues are frequently published, the results of other bilateral dialogues are less clear, as little detailed information on the outcomes is made publicly available.

- The British Standards Institution (BSI), part of the UK's innovation infrastructure, has been building a relationship with its Chinese counterpart, the Standards Administration of China (SAC) for several years. Visits and staff secondments have helped develop understanding of each other's systems, and the BSI's proposal that China be granted permanent membership of the Council of ISO (the International Organization for Standardization) was an important step towards the country's integration in the global standards system. The two sides are currently drafting a joint agreement that could help harmonise future UK and Chinese standards. David Bell, Head of External Policy for BSI thinks this 'long game' is worth it: 'it could be hugely influential in opening future trade paths, removing technical barriers to trade and giving the UK opportunities for first mover advantage in trade in emerging technologies.'[380]

Student flows from China

- The US is the first choice destination for Chinese students, hosting a total of 194,029 in 2011–12, up from 81,000 five years ago.[381]

- In the UK, there were 78,715 Chinese students in 2011–12, a 16.9 per cent increase on the previous year, making it the second most popular destination for Chinese students.[382]

- Australia ranks as China's third most popular student destination, with 75,578 Chinese citizens holding student visas in 2011.[383]

- Germany has the lowest number of Chinese students, with around 24,000 in 2012.[384] In 2011, the German Academic Exchange Service funded over 3,000 academic exchanges between Germany and China.[385]

- Germany and Australia recently extended their post–study work visa schemes[386] and the US allows students to apply for a one–year post–study work visa, if they work in a related field.

- By contrast, the UK closed its post–study work visa scheme to new applicants in 2012, and its broader stance on reducing migration flows has prompted concern in the university sector that applicants from China, India and elsewhere may be dissuaded from applying.[387]

- UK universities also have a growing presence on the ground in China. Nottingham University opened a campus in the east coast city of Ningbo in 2004. Liverpool University has partnered with Xi'an Jiaotong University to form an independent institution in Ningbo. Queen Mary, University of London has set up the Sino–British joint degree programme together with the Beijing University of Posts and Telecommunications.[388]

Future priorities

This brief and by no means comprehensive survey of how a handful of key countries are approaching their research and innovation relationship with China highlights a few lessons for the UK. First, it is vital to continue investing in the process of gathering 'innovation intelligence' on the ground in China, by ensuring we have sufficient representatives who can liaise and identify potential Chinese partners, within and beyond the obvious centres of Beijing, Shanghai, Guangzhou and Shenzhen. Second, our analysis of the bibliometric data shows that the UK is currently performing well, but this is not a strong predictor of future position due to the dynamism of the Chinese system. Third, each county's distinctive strengths and modes of engagement are unique, and while it is important to monitor and benchmark the UK's performance to that of others, the transfer of 'best practices' is rarely straightforward. Finally, the density and diversity of connections is crucial – successful collaboration strategies need to operate in an integrated way across the academic, research, commercial, trade and cultural spheres. This is a challenge to which we return in the final chapter.

8: THE REAL RISK EQUATION

Products made by Strix are used over a billion times a day. As a leading manufacturer of thermostatic controls in kettles and other consumer appliances, Strix operates in a sector with steep competition. Its drive to introduce disruptive and profitable technologies to this market has required them to invest in advanced robotics, and has generated hundreds of patents.

Working in China for well over a decade, Strix has been a target for what CEO Paul Hussey calls *"the copyists."* As he describes: *"They would take our technology and manufacture substandard components, with substandard materials and substandard engineering embedded in the product. But the price at which they could offer the product was substantially less, because they didn't have the same costs associated with producing a very high quality safe product."*[389] Frustrated with the damage to their business, Strix recently sued these rivals in the Beijing Intermediate Court. And against the odds, they won.

The process was difficult, time consuming and expensive. Yet it was in many ways a landmark case for a foreign company in China, and for Hussey, a strong validation of the positive direction of travel of the Chinese intellectual property regime. While he believes the system has matured considerably in the last few years, he is under no illusion about the challenge ahead. *"One has to see this as a long battle, because one really can't declare victory and then uproot and go home, you really have to be in it for the long haul... And I don't mean going to China once a year on a business trip. I mean moving your senior management – I've moved half my senior management to Hong Kong or China from the UK – that's a reflection of the commitment I'm making long term in this part of the world. So you have to live it, you can't just talk about it."*[390]

While some of China's bad press on risk is probably deserved, Hussey finds that the focus of mainstream media on foreign company experiences creates the sense that there is some kind of national conspiracy. *"But one forgets this simple point – last year approximately 90 per cent of all patents registered in China were registered by indigenous Chinese companies. In other words, people in China themselves have the most to lose from their own IPR system being inadequate."*[391]

In five years' time, Strix research estimates that the Chinese domestic market alone will account for 50 per cent of the global market for their products. As a result, they are gradually doing more R&D in China. *"If the entire process was a hundred steps, whereas before 90 per cent would have been done in the UK, that's more like 40–50 per cent now."*[392] It is not surprising that Hussey sees China as a massive part of Strix's future; for this company, the risk equation is clear.

Analysis of the risks of doing high–tech business in China is fraught with misperceptions and half–truths, as well as evidence of genuine challenges. For this report, we reviewed the latest available literature, but also interviewed 14 high–tech British companies which, like Strix, have experience of collaborating with counterparts in China. These 14 companies included a mix of small, medium and large companies in a range of sectors from telecommunications to semiconductors. To place their experiences in the wider context of

national policies, we then interviewed a range of government agencies in the UK, Germany, US and Australia that work to support innovation collaborations with China. Finally, we spoke to a number of expert analysts of risk in China.

For companies, a key issue is inevitably the protection of intellectual property and the freedom to exploit it. For national governments keen to engage with China for mutual benefit, the questions are often ones of international rules and governance. We address these areas in turn, with a view to presenting a balanced view of the risk equation.

Risky business?

Paul Hussey's view was widely shared among our interviewees. *"I notice the companies that are the best prepared and well organised in China tend to be the luckiest ones."*

But while preparation is key, there are persistent examples of companies with a more negative business experience in China. For Simon Knowles, founder of British semiconductor company ICERA, operating in China was a rough ride. *"Chinese equipment companies are sometimes over–focussed on unit cost reduction. Chinese customers would often take our carefully–engineered reference designs, downgrade several of the components, then demand that we fly a team of engineers to China immediately because the system did not work as specified. Going round this loop, often repeatedly, delays new product introduction and misses market windows."* He went on to say that *"Employee loyalty and respect for intellectual property in China are far below European norms today. Employees may unexpectedly disappear from your critical project, to re–appear at your competitor the very next day, and for surprisingly little financial incentive. It is necessary to construct need–to–know barriers within the company, which is an impediment to the efficiency of any engineering team."*

Examples like this are one of the reasons why even multinationals like BP and ARM are unwilling to carry out R&D on their cutting edge technologies in China. For small companies, the risks can be far greater.

Progress in the intellectual property regime

China has developed a sophisticated system of IP regulations and a patent law which largely meets WTO requirements,[393] yet enforcement hasn't kept pace with improvements in the legal framework. The US International Trade Commission estimates that US firms doing business in China lost $48.2 billion in sales, royalties and licence fees in in 2009 due to IPR infringement.[394] While these figures are debateable, the report argues that if China enforced IPR at a level comparable to the US, it would generate 923,000 additional jobs in the US.

The amount of litigation handled by Chinese courts is rocketing. Data from China's Supreme People's Court shows that China's courts accepted over 87,000[395] first instance civil IPR cases and over 13,000 criminal cases in 2012, an increase of 46 per cent and almost 130 per cent on the previous year respectively.[396] These huge jumps in the amount of patent litigation come on the back of sustained investment in China's IPR enforcement system, which now has 2,759 IP judges and 420 courts with IP divisions.[397]

Despite these improvements, the EU Chamber of Commerce in China argues that the damages awarded in IP infringement cases are too small to act as a deterrent. There are

also wide variations in enforcement between regions, with much better enforcement in first tier east coast cities compared to western and smaller cities.[398] This is what led Strix to sue copyists in Beijing rather than any other city: *"In our experience, the Beijing courts are somewhat removed from the practical realities on the ground of local influence and tend to render judgments which can be looked at more dispassionately."*[399]

Worries about IP protection in China are holding foreign companies back from bringing their cutting edge products to China.[400] Yet according to law firm Jones Day, *"The most serious IP problem for foreign business in China is that they often fail to register their IP there. China's reputation of poor IP rights enforcement had led many foreign businesses to draw the conclusion that it is not worth it to apply for patent or trademark protection in China. These foreign companies have come to regret their earlier decisions."*[401]

Ian Harvey from INTIPSA believes that *"many Western companies' problems are self–inflicted wounds,"* because they believe that *"we mustn't sue – it would annoy the government."*[402] This issue, which was confirmed by several of the interviews we conducted with SMEs for this report, is according to Harvey, a misunderstanding. He believes that the Chinese government wants companies to use the legal system and gets annoyed when they complain about poor IP protection before doing so.

While past improvements to the Chinese IPR protection system were largely driven by pressure from the US, change will increasingly be driven by domestic pressure in the future.[403] Denis Simon argues that as the government has increasingly come to rely on enterprises to drive innovation, Chinese companies have started to voice their demands for improved IPR protection. Japan, Taiwan and South Korea all strengthened their IPR protections when they moved from low–cost manufacturing to R&D and design, and Simon argues that China will be no different.[404]

However, there are questions, both within China and abroad, about the role that the patent systems of developed countries play in promoting innovation and economic growth. The Hargreaves review (2011) of the UK IP system found that the increase in patent filings over the past decade has led to a backlog at the UK patent office and created 'patent thickets', which it defines as 'an overlapping set of patent rights.' It finds that both of these problems exclude firms from entering the market and inhibit growth.[405] To convince China of the value of improving its IP system, developed countries should recognise and be open about the problems in their own systems. But they could also benefit from a better understanding of the Chinese patent system and the reforms that are happening there. Experts believe the smaller number of patent rights owners in China gives the government more space to enact reforms than would be the case in Western countries. Furthermore, the future development of global IP norms may shift from the US to China as the centre of global economic power shifts east making a understanding of the Chinese system even more important.

Mitigating IP risks

A number of factors affect the relative level of risk that a high–tech company faces when collaborating in China, and a variety of strategies can be deployed to overcome these.

In terms of patent infringement and IP theft, there is clearly a greater risk for companies whose products are more easily reverse engineered. As Zhenhui Gou, General Manager of the Chinese subsidiary of Lucy Switchgear, a family owned SME that designs and manufactures switchegear for electric distribution networks pointed out, *"Our industry is a*

more traditional industry, so a competitor doesn't need to come to our factory and steal our technology, they just need to buy our product and open it up."[406] Here reputation as a high quality brand is as important to protecting revenues as a patent *"people in the industry know the difference between our brand and others, the quality is much higher."*[407]

There is less risk of impact for those companies with more advanced products and processes. Paul Thorning, director of open innovation at the University of Bradford and founder of a pharmaceutical start up in China, told us that *"it could take a company several years to replicate the process for creating our product."* For Steve Cook, Strategy Advisor at BP, the position was similar: *"BP mostly licences process and process technologies to China. Simply having a patent doesn't enable you to make a process work, you need the know how, such as trade secrets, which are not published."*[408]

While intellectual property is clearly of huge value, companies reiterated that it was only one component of creating value from research and innovation. For Strix, *"It is one thing to put something on a blueprint, but it's quite another to manufacture it in mass production to a high level of engineering."*[409] While Xiangming Xu of East Malling Research believes that *"even if our IP gets stolen, it's unlikely that Chinese companies would have the ability to sell their products in UK markets immediately."*[410]

Global market share in an industry is another factor limiting the impact of IP theft for large companies. COO of semiconductor multinational, ARM, Graham Budd is clear that the company is committed to a long and successful engagement in China. Yet it remains careful about the type of technology it takes into the country. *"We don't feel ready yet to develop our 'crown jewels' IP in China. However, our business model is self–policing to an extent. Our IP is in the hands of many companies. It could easily leak out. But if that happens and if a company is looking to be successful in high volume product, they would be mad to try and create a product without coming to us for a licence, due to the risk of using unvalidated IP, and the risk of shipping an end product created without our engagement and support. If an organisation stole our IP and only used it for research or only shipped a few products, there would be very little lost revenue due to our royalty business model."*[411]

Similarly for Imagination Technologies, a global IP company, which in addition to developing and licensing silicon, software and cloud IP also designs and manufactures consumer products, in the majority of cases there is a moderately low risk of competitors being able to use copies of advanced technologies to compete with them. As part of ramping up engagement with China, they licensed technologies to a range of Chinese companies including Huawei. Imagination started working in China more than seven years ago, and for Tony King–Smith, an Executive Vice President at Imagination, the current environment for doing business is *"China 2.0."* Chinese companies in the past used to be *"pretty aggressive"* in their efforts to get hold of technology. However, as their interactions with the West and other markets increased, the overall commercial operating environment has similarly matured considerably. While earlier licensing deals usually were only for older generations of their technology, Imagination recently made the decision to license even their cutting edge technology in China. *"Our industry is global, and the Chinese are heavily dependent on Western technologies and markets to be successful. These companies cannot afford to be seen as 'dangerous' from an IP perspective by the rest of the industry, so we're seeing a much more sophisticated and mature approach to doing business with leading Chinese partners now that encourages us to invest more into China."*[412]

Some believe that the best way to protect IP assets in China is by not relying too much on any single partner or customer in China. Despite efforts to spread intellectual assets, there are high–profile cases of trade secret theft in China. American Superconductor Corporation (AMSC) supplied power systems and software to the Chinese wind turbine manufacturer

Sinovel and is now suing it for $1 billion after it paid an AMSC engineer to steal its source code.[413] Some believe AMSC should serve as a cautionary tale to companies of how not to do business with China: Sinovel accounted for 75 per cent of AMSCs revenues before its IP was stolen.[414]

Another approach is through investing considerable time in developing long–term, trusting relationships with Chinese counterparts.

Graham Budd, COO of ARM clarifies their approach. *"We feel that it is more important to engage and develop partnerships in China rather than just trying to sell over there. China is moving very fast, so you need to engage not just sell, otherwise there is a risk that someone else will do what you do cheaper and faster and you will find yourself designed out of the process."*[415]

Ultimately though, our interviews suggested that the best way for a company to protect itself is to stay ahead of their competitors by constantly innovating. Several of our interviewees echoed the view of Jenny Norris, research director of the European Marine Energy Centre (EMEC): *"EMEC's preferred approach is to stay ahead of the game, to ensure that we are the obvious partner to come to and seek assistance from (in the form of consultancy). With the difficulties associated with international law, I don't think we would have much faith in our ability to uphold an NDA were it to be abused: at the very least you'd end up with a massive bill and no substantial progress, so it's better to be more proactive about it and look to stay ahead in the first place."*[416]

Beyond 'traditional' forms of IP theft and leakage, a surge in global media reports has focused attention on the issue of cybercrime and hacking emanating from China.

Cybersecurity

In a speech to the Asia Society in March 2013, Tom Donilon, National Security Advisor to the President said that *"Increasingly, US businesses are speaking out about their serious concerns about sophisticated, targeted theft of confidential business information and proprietary technologies through cyber intrusions emanating from China on an unprecedented scale."*[417]

A report for the Cabinet Office by the consultancy Detica found that cybercrime costs the UK £27 billion/year, £9.2 billion/year[418] of which can be attributed to IP theft. However, this report has received much criticism for its methodology.[419]

Paul Cornish, Professor of Strategic Studies at the University of Exeter argues that *"where the quantified effect of cyber espionage is concerned, the evidence is at its most incomplete and flawed and the debate at its most speculative and contentious."* He says that while there is a growing amount of evidence of Chinese cyber espionage, *"there is, as yet, far less clear evidence as to the damage caused by Chinese cyber espionage."*[420] Jason Straight of the risk consultancy Kroll argues that risks to innovative companies from cybercrime are overplayed compared to traditional channels for IP theft, *"businesses need to avert their gaze from high–profile, state–sponsored cyber threats and look at their people."*[421]

While data security was on the risk agenda of many of the companies we interviewed, most suggested that it was not an overriding concern. It is, however, playing a significant role at a political level, most prominently in increasingly hawkish US rhetoric on this issue.

Innovation collaboration and the national interest

Over the last decade, a growing number of countries, including the UK, have recognised the importance of innovation in spurring national economic growth and competitiveness. National innovation agencies are proliferating in developed and developing economies as governments seek to develop the suite of policies that will help them both collaborate and compete in a rapidly developing global system. US think tank ITIF suggest this is resulting in a range of 'good,' 'bad' and 'ugly' approaches to innovation policy.

"Countries can implement their innovation policies in a win–win, positive–sum fashion that simultaneously spurs domestic innovation, creates spillover effects that benefit all countries, and encourages others to implement similar win–win policies. But another path countries all too often take seeks to realize innovation–based growth through a zero– or negative–sum, beggar–thy–neighbor, export–led approach."[422]

For ITIF CEO Rob Atkinson, co–chair of the US–China academic innovation dialogue, China's policies can tend towards the ugly: *"China wants to compress a 40–year learning process into ten years. The only way for China to achieve this great leap forward is by free riding on foreign technologies. Examples include forced technology transfer, indigenous innovation product catalogues and IP theft, with key cases ranging from companies such as Nortel (a post–bankruptcy report revealed China had been 'inside' Nortel systems since 2000), American Superconductor (trade secret theft) and Ford (where entry into the Chinese market required a forced joint venture and construction of R&D lab)"*[423]

ITIF is working from a US system that has appeared increasingly 'hawkish' about collaborating with China on research and innovation. According to cyber security expert Adam Segal of the Council of Foreign Relations *"The slow leaking of stories about hacking, and then the deluge of them in the last six months, and the evidence that they are connected to China's S&T plans, this has really changed the environment."* Yet despite congressional efforts to limit collaboration in areas sensitive to the national interest, such as space, US–China collaboration continues to deepen as described further in Chapter Seven.[424]

An effective dialogue on innovation policy cannot overlook the role of national innovation policies on international competitiveness. Below we consider three areas of concern: market access restrictions and the lack of a level playing field, technology transfer conditions and technology standards.

Towards a level playing field?

In its 2013 business confidence survey, the EU Chamber of Commerce found that 45 per cent of European companies had missed opportunities in China due to market access restrictions.[425] Many of these restrictions are legally defensible because China isn't yet a signatory to the WTO's Agreement on Government Procurement.[426] The EU Chamber of Commerce calculates that public procurement in China represents over 20 per cent of the economy – potentially a huge market for European companies if access to information and transparency were improved and contracts were awarded fairly.[427] The United States Trade Representative's latest report to Congress on China's WTO compliance states that despite improvements over the past decade, subsidies, market access barriers, and discrimination against foreign companies all continued to be issues of concern in 2012.[428]

A recent case that generated much discussion among policy communities was the indigenous innovation product accreditation scheme. As outlined in ITIF's report *The Good, the Bad and the Ugly*, eligibility for preferences under the original programme

required products to have Chinese proprietary intellectual property rights and an original registration location of the product trademark within the territory of China. While domestic content is often a requirement of national procurement policies, the inclusion of IP ownership requirements lay far beyond standard practice. For ITIF, the wind energy equipment industry is the best example of the result of similar policies, which led foreign wind turbine producers' share of the Chinese market 'crater' from 75 per cent in 2004 to 15 per cent in 2009.[429] Most recent figures show that in 2012 it fell further to around 7.5 per cent.[430] The 70 per cent local content requirement on wind turbines was removed in 2009 as a result of US lobbying,[431] but this has been viewed as a largely symbolic gesture, as by that time Chinese manufacturers had already cornered the market.[432]

Subsidies to Chinese manufacturers have also been a large source of tension between China and developed countries. While it is difficult to get a full picture of the subsidies on offer, as many are given by local governments in the form of free land and tax deductions, it is undeniable that Chinese industry has benefited hugely from them, with some estimating that they account for as much as 30 per cent of China's total industrial output.[433] However, as mentioned in Chapter Seven, many countries are reluctant to take action against China, fearing retaliations in the form of tariffs on their own exports to China. The US is more willing to place tariffs on Chinese products, such as solar panels, but has suffered retaliation in the form of tariffs on its own exports of polysilicon to China,[434] precisely the outcome that EU countries worry about.

Technology transfer: at a fair price?

China's WTO commitments prohibit it from making technology transfer a requirement of market access.[435] However, in recent years Westinghouse (nuclear reactors), Kawasaki (high–speed rail) and GE (avionics) have all transferred core technologies to Chinese partners to gain access to the Chinese market.

To take one of these examples, Westinghouse, the US–Japanese nuclear reactor manufacturer, agreed to transfer over 75,000 technical documents to its Chinese partner in order to win a contract for the construction of its AP1000 nuclear reactor in China.[436] Jack Allen, president of Westinghouse Asia, believes that even with the technical information, China won't be able to compete with Westinghouse in the next few years. He also argues that past giveaways of technology have led to relationships with other countries which have lasted 20 years. Yet already in early 2013 China started marketing its own version of Westinghouse's reactor, the CAP1400, to international clients in South Africa.[437]

Among the companies we interviewed, decisions about technology transfer were taken on a purely commercial basis. As China's absorptive capacity increases, the nature of technology transfer is developing. BP told us that in strategic industries, *"the requirements are becoming more and more onerous. We are asked to train staff, co–develop IP and share future technology plans."*[438] However while this is a feature of working with China, it is just as much an issue in other places around the world, for example the Middle East.

Companies like these are often criticised for giving away their technologies, however GE and Westinghouse argue that they know what they are doing and have built precautions into their joint ventures and technology transfer agreements.[439] Indeed, Chinese officials feel that these agreements generally haven't given China the cutting edge technologies it desires, as many companies refuse to bring their most advanced technologies to China.[440]

National governments are likely to have a far longer–term viewpoint of these decisions than companies. As Rainer Frietsch of Fraunhofer ISI argues *"Policymakers and businesses*

have different reasons for collaborating with China. Policymakers have more general goals concerned with social needs and benefits for society, whereas companies have to think of their own benefit and performance. It's simply a different game."

Standards: from going it alone to global engagement?

There are over 15 million iPhones registered on the China Mobile network and all of them are limited to a 2G signal.[441] This is because in its 9th Five Year Plan, China committed to developing its own 3G standard[442] and today China Mobile uses the proprietary TD–SCMA standard, which isn't supported by Apple.

The USTR notes that *"China seems to be actively pursuing the development of unique requirements, despite the existence of well–established international standards, as a means for protecting domestic companies from competing foreign standards and technologies."*[443] It lists several areas which China is pursuing standards in: cars, mobile phone batteries, RFID technology and telecommunications, among others. Examples of standards developed in China include WAPI (wireless internet), TD–SCMA (3G) and TD–LTE (4G).

In *China's drive for indigenous innovation* James McGreggor notes that *"With the government controlling standards, certification and testing regimes can be formidable tools for protectionism."* However, others believe that China's standards policies need to be understood as part of China's development strategy which it is using to catch up with high income countries[444] and Dan Breznitz argues that standards have been most effective as a trade tool to reduce royalty payments on foreign IP.[445] While early work in standard setting wasn't very successful technically, China is now an active participant in international standard setting.[446]

Positive sum games

For many companies, as in the case of Strix at the start of this chapter, China is simply 'too big to ignore.' There are no doubt increased risks of operating in such a vast, dynamic and sometimes chaotic system. But despite these, most companies recognise that these are inevitable features of a maturing economy. The nature and level of risk varies considerably by industry, by size of company, by national economy and also by region within China. Monolithic strategies to counteract these risks are unlikely to be effective and smarter communication from government which is both tailored, and makes use of all available intelligence, will help companies make a more accurate assessment of the risks of engagement.

Innovative companies recognise better than most that without some risk, there is little reward. Intellectual property is only as valuable as one's capacity to exploit it and stay ahead of the competition. While our interviews confirmed that perceptions of risk put some companies off taking their cutting edge products to China or carrying out advanced R&D there, we would argue that the greatest risk for companies is of focussing too much on these downsides, and missing out on the enormous opportunities that China presents.

For national governments, China is also too big to ignore and is already having a more tangible influence on structures, policies and standards for innovation. Some argue that greater pressure is required to encourage China to look beyond its national interests and confirm to international norms. But again, the unparalleled scale of the opportunity from collaboration with China – for the UK and others – makes the risk equation relatively easy to solve.

9: CHINA–UK: PARTNERS IN THE GLOBAL INNOVATION RACE

Thirty years ago, in 1983, China was shaking off the last vestiges of the Cultural Revolution. Its per capita GDP of $223 placed it on a par with Ethiopia,[447] and over 90 per cent of the population was living on less than $2 a day.[448] The first batch of university students for over a decade had just graduated,[449] 270,000 students had been admitted in that cohort, 0.03 per cent of China's population at the time. And an influx of foreign investment was just beginning to transform the Special Economic Zones, which had recently been established in the southern cities of Shenzhen, Zhuhai, Shantou and Xiamen.[450]

Fast forward 30 years to 2013, and the country is almost unrecognisable. China is now the second largest economy in the world. It produces almost 13 per cent of the world's scientific papers and has 25 per cent of its R&D workforce, and over six million of its students will graduate this year from higher education.[451] China's increasingly sophisticated innovation system has succeeded in combining all of that home grown skill and knowledge with foreign technologies to build the world's fastest supercomputer, send astronauts into space and pioneer the Beidou Satellite Navigation System.

And what if we now cast our minds forward 30 years? In the year 2043, China will be only seven years away from becoming a 'world leader in science and technology', the target set by the 2006 MLP. It will have been the world's largest economy for well over 20 years,[452] and an 'innovation oriented society' for over a decade. But the China of 2043 will also face acute challenges: almost a third of its population will be over 60; its environment is likely to have deteriorated as a consequence of climate change; and its broader social and political trajectory is unclear.

However the narratives of China's future described in our opening chapter combine, overlap and play out – and whatever surprises emerge along the way – there is little doubt that China's role as an innovation power will be even more pivotal in 2043 than it is today. For the UK, the choice is not whether to engage more deeply with the Chinese system, but how.

UK policymakers have long recognised the need for a closer relationship with China on research and innovation. A headline conclusion of this report is that China's innovation system is advancing so rapidly in multiple directions, and is now so absorptive, that the UK needs to develop a more ambitious and tailored strategy, able to maximise opportunities and minimise risks across the diversity of its innovation links to China.

Prime Minister David Cameron has spoken frequently in recent months about the 'global race' that is now underway. The notion of a race is helpful in focusing political, media and public attention on the competitive challenges that the UK now faces. But it can perhaps imply that there is some kind of fixed prize or absolute advantage at stake, rather than the comparative advantages, and mutually beneficial niches, which make up networks of international trade, research and innovation.

Charles Leadbeater and James Wilsdon summarised this argument in the introduction to *The Atlas of Ideas,* which drew on Demos' 2007 China study and linked reports on India and South Korea:

"The rise of innovation from China, India and Korea is feeding a climate of anxiety in Europe and the US that could lead to defensive responses…(It) will inevitably challenge our position in knowledge–based industries. More knowledge jobs will go offshore. Research and development will become more international. In the long run, China, India and Korea will start to earn more from exploiting their own intellectual property, and our share of income from intellectual property may decline. However, it would be extremely short–sighted to view these developments purely as a competitive threat…

Innovation in China will continue to accelerate development and raise incomes, creating a larger market for British services…If more researchers are doing more science, with ever more powerful computers, this increases the likelihood of meeting the global challenges we face: from low–carbon innovation to vaccines against pandemics. More brains, working on more ideas, in more places around the world, are good news for innovation."[453]

In the global innovation race, it is clear that there can be more than one winner. The question we explore in this final chapter is how can China and the UK become closer running mates, more effectively playing off each other's strengths?

How much has changed since 2007? Ten key findings

One striking change since the 2007 Demos report is the extent to which the quantity and quality of evidence, data and international analysis of the Chinese innovation system has improved. There is now less hyperbole about numbers of engineering graduates or the volume of R&D investment, and more balanced, fine–grained discussion of the progress and obstacles that China is encountering on its path to becoming a more innovative economy.

In this report, we set out to understand the latest developments and future prospects for Chinese innovation, with a view to developing a more strategic framework for China–UK collaboration. To do this, we drew on over 600 reports and articles published in the last five years, we commissioned and analysed new quantitative datasets, and we conducted expert interviews with policymakers, academics, business leaders and research funders. Below we summarise our ten most significant findings:

1. **China is an absorptive state, increasingly adept at attracting and profiting from global knowledge and networks.** China's growing innovation system has succeeded in combining rapidly improving home–grown capabilities and infrastructure with foreign technologies and knowledge to build the world's fastest supercomputer, send astronauts into space and pioneer the Beidou Satellite Navigation System. These examples suggest that what China's President Xi Jinping terms *"innovation with Chinese characteristics"* will not be a straightforward path from imported to home–grown innovation, but a messier process in which the lines between Chinese and non–Chinese ideas, technologies and capabilities are harder to draw.

   Characterising China as an absorptive state helps us to understand its current phase of development: that the systemic conditions for research and innovation have reached a stage where ideas can be effectively absorbed and exploited, with increasingly dense and targeted networks to enable this. But it also helps us assess the prospects for future

development: absorption will remain a core strand of national research and innovation policy, and Chinese firms' impressive ability to rapidly absorb and re–innovate, while adding novelty and value to ideas and technologies in the process, is crucial to understanding their competitiveness.

2. **Accelerating the shift to a more innovative economy remains a core priority of China's new leadership, yet equally important is a new focus on quality, efficiency and evaluation.** A policy focus since the early 1990s on investment and growth has propelled China into the top ranks of global innovation, but the process has been inefficient and these policies are now being complemented by a growing focus on efficiency, quality, coordination and evaluation. This trajectory of reform is likely to be consolidated in the 2016 13th Five Year Plan.

3. **The exceptional growth trajectory of China's research base continues, but has not yet been matched by similar leaps in quality.** Growth in output is pervasive throughout the system, both in large fields such as engineering and in newer fields such as biomaterials, which grew 15–fold in the last decade. Impact remains below world average in most areas, but is close to that benchmark in a number of fields, including engineering and mathematics, and consistently above average in agriculture. The strengths of established research economies like the UK are relatively stable from year to year, while China's are changing at an unprecedented rate. This requires a cautious approach to interpreting strengths and weaknesses. Spikes of excellence and pools of mediocrity can be hidden among the averages.

4. **Research and innovation is still highly concentrated on China's east coast, but diverse models of innovation are visible among east coast hotspots.** While some second tier inland cities such as Chengdu and Wuhan have benefited from government and multinational investment in innovation, well over two–thirds of all patents were granted to applicants on the east coast in 2011. In addition, the east coast accounted for over 60 per cent of China's publication output. Yet among the eastern hotspots of Beijing, Shanghai and Guangzhou, there are contrasting innovation models. While the central government sets the overall policy context, targets and evaluation metrics, there is a considerable degree of autonomy in how to deliver on these goals in different places, leading to experimentation through different interpretations of national policies.

5. **Over the last five years, an expanding tier of Chinese multinationals have become visible in global rankings of firm–level innovation.** Both Baidu and Tencent appear in the top 50 of *Forbes'* list of most innovative companies and ZTE applied for more PCT patents than any other company in the world in 2012. China has benefited considerably from the fragmentation and modularisation of global production, which has allowed its enterprises to specialise within particular niches of product and service value chains. Businesses are responsible for almost–three quarters of China's R&D spend, but progress towards an enterprise–led innovation system has been inhibited by the slow pace of reform in state–owned enterprises.

6. **Previously regarded as a weakness, the quality and speed of China's capacity for incremental re–innovation is now an important competitive asset.** Sophisticated manufacturing networks excel in absorbing, adapting, prototyping and market testing new products and technologies at speed. 'Shanzhai' methods of production previously referred only to substandard imitation, but as former shanzhai companies have developed disruptive products, this method of innovation is of growing international interest as a distinctive way of adding value. These approaches are not only prevalent in manufacturing, but also in the digital and creative industries.

7. **After three decades of rapid economic growth, debate in China is intensifying about how to direct innovation towards social and environmental goals.** Environmental and health concerns are prompting a sharper focus on low–carbon and sustainable innovation and the government is investing heavily in low–carbon cities, renewable energy and energy efficiency programmes. A more proactive and vocal civil society is at the forefront of growing calls for social innovation. More demanding Chinese consumers are driving new types of user-driven innovation, a process which will intensify as domestic consumption takes over from investment as the main driver of China's economic growth.

8. **Our new analysis shows that in 2011, the UK overtook Japan to become second only to the US in the number of its joint research publications with China.** The UK has increased its share of China's collaborative activity while other EU countries have declined. This is an encouraging sign but a weak predictor of future performance, owing to the speed of change within the Chinese system. For any country seeking to collaborate with China, ensuring a density and diversity of connections will be crucial, spanning the academic, research, commercial, trade and cultural spheres.

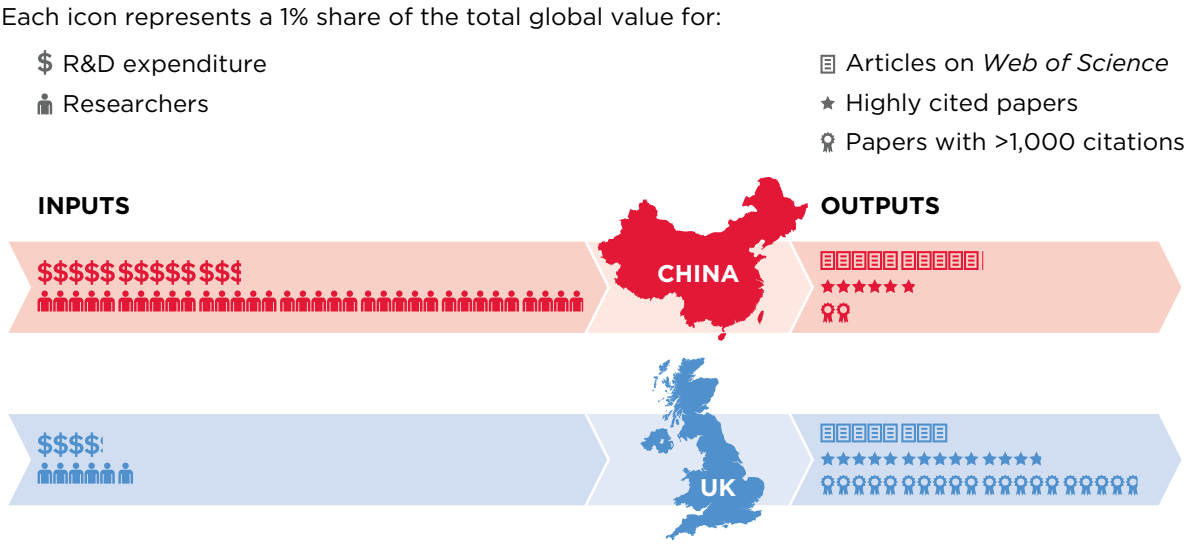
9. **There is no perfect formula for high impact collaborations with China.** There is very little evidence available on the effectiveness and economic impact of different models of support for international innovation collaboration. Each county's strengths and modes of engagement are unique, and while it is important to monitor and benchmark the UK's performance against that of other countries, and learn from other countries' experience, the transfer of 'best practices' in collaboration is rarely straightforward. For instance the US and German approaches to collaborating with China are frequently held up as models for the UK to emulate. However, the UK's economy and military might is substantially different from that of the US and its manufacturing base contrasts with the one which forms the foundation of the Sino–German relationship.

10. **The greatest 'China risk' for innovative companies is focussing too heavily on downside risks, and missing out on the opportunities that China presents.** Hawkish perspectives on Chinese innovation highlight the 'dark side' of China's absorptive state: international flows of ideas and technology resulting from IP theft, forced technology transfer and hacking. But innovative firms recognise that without some risk, there is little reward. Intellectual property is only as valuable as one's capacity to exploit it and stay ahead of the competition. The increasingly absorptive Chinese system brings both risks and opportunities for businesses, universities and others seeking to work with and in China. These risks need to be managed with care, but they should not be over–emphasised to the extent that they eclipse a far greater risk – that of failing to participate fully and benefit from the next phase of China's growth.

A more strategic approach to China–UK collaboration

President Xi has outlined his vision for a new partnership between the major powers. While the UK may not have the military or economy the scale of the US, or the geopolitical significance of Russia, it remains a major power in research. With less than 1 per cent of the world's population, the UK produces 8 per cent of the world's publications, 14 per cent of highly–cited papers and 19.8 per cent of papers with over 1,000 citations. The UK's strong performance has been maintained in recent years, despite flat levels of public funding for research since 2010, as the UK, like other countries, has dealt with the aftermath of the global financial crisis.

Figure 18: **China and UK: comparing the productivity of research systems**[454]



The UK's innovation system is also highly internationalised and attractive to foreign R&D investment, with firms more likely to be active in foreign markets than many European counterparts and an unusually high proportion of R&D funded from abroad.[455] Like any country, its system is not perfect: Nesta research has shown that investment in innovation by UK–based firms has fallen since the global financial crisis,[456] and the proportion of government support directed towards development remains low compared the USA, Germany and Finland.

Both China and the UK have much to gain from a deeper and more strategic set of connections across their innovation systems – from accessing new markets, to exploiting each other's' capabilities and facilities, to collectively shaping the future norms of the global innovation system. A first step is to assess the current health of China–UK collaborations. While this report has made useful progress here, it also shows that the UK needs to get better at articulating, demonstrating and evaluating high value approaches, and aligning future strategies with these.

As we describe in Chapter Seven, links across the academic research base are strong, with a growing volume and share of co–authored publications. China and the UK have also enjoyed success over the past five years with various collaborative research schemes, which have combined the best of a researcher–led 'bottom–up' system with greater 'top–down' prioritisation. The expansion of the FCO/BIS Science and Innovation Network in China, and the presence of a small RCUK team in Beijing, have helped to make China–UK collaboration more targeted and strategic.

Analysis of the impact of joint research showed that China gains considerably from collaborations with the UK, and that the UK gains at the high impact end. The bibliometric data in this report provides many useful insights into academic research links, but it also highlights the lack of equivalent indicators with which to assess the wider China–UK relationship in innovation and the value that this creates. Tools and metrics for assessing research collaboration at one end of the spectrum, and international trade flows at the other, are very well developed. But there is a 'missing middle' in terms of measuring and evaluating the value chain connections that comprise global innovation partnerships.

There are no proven methods for determining the greatest areas of strategic opportunity for collaboration. Australian government analysis highlights China as a strategic research partner since China's research strengths are generally in areas of Australian weakness and vice versa. Other countries may prefer to collaborate only in areas of mutual excellence. For the UK, a 'strategic' area of collaboration could be materials science, where China's research base is already strong. However, thinking long term, some might suggest it is strategic to collaborate with China on biomedical science, where the UK is far stronger, despite pockets of excellence in China (e.g. Fudan University), but where China's large and rapidly growing research base could help scale up UK activity and future commercial opportunities. But at a time when the UK is adopting more targeted industrial and technology policies, there are more potential synergies with the Chinese approach to strategic prioritisation than at any point over the past 30 years. For example, David Willetts, the UK's Minister for Universities and Science, has highlighted 'eight great technologies' where Britain has distinctive research capabilities and is well placed to take advantage of emerging markets.[457] These are big data, space, robotics and autonomous systems, synthetic biology, regenerative medicine, agri–science, advanced materials and energy; domains which are also strengthening fast within the Chinese system.

China–UK collaborative research and innovation can only flourish within an open, trusted and transparent economic and regulatory system. As we discuss in Chapter Eight, there are undoubted risks of working in and with a system that is still developing. The nature and level of this risk varies considerably by industry, by size of company and by region within China. Some companies are clearly discouraged from working with China because of concerns such as IP protection and cybersecurity. But as the Judge Business School's Peter Williamson argues, the risks of not engaging with China are greater still: *"The real race is all about exploiting quicker and faster. We always look at data on loss and technology leakage and forget to assess the value of missed opportunities!...This conservatism in thinking has not kept up with the reality of global value chains."*[458]

Ministers and officials in China's MoST and the UK's BIS are aware that many policies and incentives for innovation lie beyond their formal remits, in other departments, in businesses and across the wider economy. Debates are ongoing in both China and the UK about how to design and deliver innovation policies that can maximise quality and effectiveness.[459] For both governments, processes such as the China–UK economic and financial dialogue, the Joint Commission on Science and Technology and the Innovation Policy Dialogue are important routes to improving trade flows, market access and IP protection across the Chinese, UK and EU systems.

Four recommendations

Building on the analysis of this report, we end with **four practical recommendations** for ways in which China–UK innovation links can be strengthened to mutual advantage:

1. **The UK should develop a new five-year strategy for China–UK collaboration in research and innovation.**

   Work towards this strategy should begin now, but 2016 would be the ideal time to publish it, in order to take account of new policies in China's 13th FYP, and the 2015 post-election Spending Review in the UK. The strategy should encompass the full breadth of potential innovation links between the two systems, from research through to the commercialisation, demonstration and scaling phases of new technologies. Some programmes should envisage a horizon of decades rather than years, and this strategy should be fully embedded in a long-term plan for innovation-led economic growth in the UK. Stable long-term investments and incentives should help experimental approaches to collaboration flourish. On the UK side, this process will require the active involvement of the Technology Strategy Board and a wide range of industrial and business partners in addition to BIS and RCUK.

2. **The UK should develop more sophisticated methods and metrics for identifying China–UK innovation opportunities and for evaluating impact.**

   The strategy should look beyond readily measurable research performance and patenting data to understand China's evolving specialisms. It should explore how UK companies can better engage with China's strengths in developing, iterating and scaling technologies. The UK should develop approaches to supporting ecosystems of collaboration rather than individual companies. The UK's 'eight great technologies' should form the basis of a mapping exercise to determine specific China–UK complementarities, which should feed into the five-year strategy. Bibliometric data should be used to expand and diversify research collaborations, by developing a data resource for UK researchers, identifying the range of Chinese universities where they can find relevant capacity and competence. One of the strengths of UK innovation policy is the high degree of openness and debate about the effectiveness of different approaches. Much equivalent debate and analysis takes place on the Chinese side, but is often difficult to access online. The UK government should encourage Chinese counterparts to promote access to data and analysis on innovation policy in the same way the UK has on the gov.uk website.

3. **Expand the China–UK innovation policy dialogue to include a new bilateral expert group, able to undertake in-depth analysis to inform ministerial meetings**

   China and the UK should expand their existing innovation policy dialogue to establish a group of Chinese and UK experts in research, innovation and industrial policy, able to explore themes relevant to collaboration and provide input and advice to official discussions. This group could analyse emerging policies and what they mean for each country, evaluate programmes and methods used to support collaboration, and assess Chinese and UK strengths and weaknesses for areas of complementarity. Crucially, the work of the group should be published, to inform public debate on UK–China collaboration.

   The new expert group would monitor, conduct research and report publicly on major areas of interest to the China–UK innovation relationship. With a strong focus on

collaborative opportunities, the group would analyse emerging policies and what they mean for the each country, evaluate programmes and methods used to support China–UK collaboration, and analyse Chinese and UK strengths and weaknesses to identify areas of complementarity. Focused analysis could also be undertaken under priority themes spanning research and innovation, for example:

- **Ageing and healthcare:** Both countries face the challenge of caring for an expanding elderly population with a dwindling workforce. Innovations in health technology, and systemic approaches to transformation could be explored.

- **Smart and sustainable cities:** China has been investing heavily in smart and eco–cities, and efforts have been made to match Chinese demand to UK strengths in design, construction and big data. But this is an area that can only grow in importance given the pace of urbanisation in China.

- **Creative industries:** China is now making significant investments in cultural institutions and creative industries, and is a huge potential market for the UK. Creative industries are an area of great strength for UK innovation and there are considerable unexploited opportunities for collaboration around for instance cluster development and intangible investments in innovation.

4. **Further boost the UK's presence and capacity in China to coordinate innovation diplomacy and collaboration for greatest economic and social impact.**

The UK needs to invest further to ensure it can sustain the full range of activities required for an effective approach to innovation diplomacy that will unlock long–term economic opportunities for the UK. This will require brokers and intermediaries capable of supporting a full spectrum of relationships. They should recognise when to support individual or supply chain–based collaborative efforts and when to shift attention to transforming the overarching policy environment. They also need to ensure better coordination between UK partners in China. As the global innovation system develops, the UK should design more targeted policies to increase its own capacity to absorb, develop and exploit knowledge as well as to generate it. The proposed expert group should work closely with UK representatives on the ground to gather data and identify opportunities and draw lessons from effective practices.

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GLOSSARY

BBSRC	(UK) Biotechnology and Biological Sciences Research Council
BERD	Business Enterprise Research and Development
BIS	(UK) Department for Business Innovation & Skills
CAS	Chinese Academy of Sciences
CASTED	Chinese Academy of Science and Technology for Development
EPSRC	(UK) Engineering and Physical Sciences Research Council
ESI	Thomson Reuters Essential Science Indicators
ESRC	(UK) Economic and Social Research Council
FCO	(UK) Foreign & Commonwealth Office
FDI	Foreign direct investment
FYP	Five Year Plan
GDP	Gross Domestic Product
GERD	Gross domestic expenditure on R&D
GNI	Gross National Income
IPO	UK Intellectual Property Office
ITIF	Information Technology and Innovation Foundation
MIIT	Ministry of Industry and Information Technology, People's Republic of China
MLP	Medium and Long-term National Plan for Science and Technology Development 2006–2020
MOFCOM	Ministry of Commerce, People's Republic of China
MOST	Ministry of Science and Technology, People's Republic of China
NSF	(US) National Science Foundation
NSFC	The National Natural Science Foundation of China
OECD	The Organisation for Economic Co-operation and Development
ONS	(UK) Office of National Statistics
PCT	Patent Cooperation Treaty
RCUK	Research Councils UK
SASAC	State-owned Assets Supervision and Administration Commission, People's Republic of China
SIN	(UK) Science and Innovation Network
SIPO	State Intellectual Property Office of the People's Republic of China
SOE	State Owned Enterprise
TSB	(UK) Technology Strategy Board
UKTI	UK Trade and Investment
UNESCO	United Nations Educational, Scientific and Cultural Organization
USPTO	United States Patent and Trademark Office
WIPO	World Intellectual Property Office
WoS	Thomson Reuters' Web of Science
WTO	World Trade Organisation

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Additional experts were consulted in confidence

ENDNOTES

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ISBN 978-1-84875-148-4

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