An Innovation System for the 21st Century? Reflections on China's Science and Technology Reforms

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In its latest "Science, Technology and Industry Outlook," the OECD has called attention to the rapid rise of China's research and development expenditures and the likelihood that Chinese spending on R&D will surpass that of the US in the not-too-distant future. A growing number of indicators point to rapidly improving capabilities in Chinese science and technology, suggesting that expenditures have produced results. These signs of progress include increasing numbers of papers published in international journals, increasing numbers of patents, a large and expanding community of scientists and engineers, and the successful completion of demanding research and engineering projects in such fields as space, ocean engineering, supercomputing, transportation, materials science, etc. These indicators all point to considerable success in implementing policies for catching up with international scientific and technological frontiers.

Yet, one of the more curious aspects of scientific and technological development in China over the past 15 years has been that rapid spending increases on research and development have occurred in the face of an institutional environment that has been unsettled, has not always been well-suited to the effective use of generous funding, and has therefore been subject to rounds of reforms. Since 2000, and the beginning of the R&D expenditure surge, spending has clearly outpaced institutional design.

Not surprisingly, therefore, careful observers both inside and outside of China have been aware of the fact that many of the positive indicators of progress have obscured serious problems with China's science and technology development, especially as China seeks to go "beyond catch-up" to positions of techno-scientific leadership. These range from serious problems of scientific misconduct, widespread filing of low-quality patents, waste and misuse of R&D funding, and the development of a technical talent pool, a large portion of which seems to lack the training and socialization needed for original research. And, in spite of calls for "indigenous innovation," reliance on foreign science and technology for major national research and engineering projects remains high, reflecting ongoing problems of technological dependency.

In short, despite the substantial investments China is making in science and technology, the resulting research accomplishments, technological innovations, and the creation of the innovative society envisioned in current national plans, have been seen as disappointing by key decision makers. Questions about further reform of the innovation system are therefore again on China's crowded policy agenda, being interlinked with economic reforms intended to strengthen market forces and reduce the role of the state, with reforms focused on legal status of "public service organizations" (*shiye danwei*), and with the widespread anti-corruption initiatives.

Although the current S&T reform program is focused on the abuses and weaknesses of the current system, several larger questions loom in the background. To what extent is the reform program preparing the way for dealing with the challenges of innovation in the 21st century? Will reforms, if successfully implemented, lead to unanticipated problems that will require further reforms after several years, or will they lead to institutional solutions with a high level of sustainability? Do they offer policies and institutions that will permit the Chinese innovation system to move "beyond catch-up" to international leadership in science and technology?

Mapping the Problems.

Reforms in the Chinese science and technology system are hardly new. Over the past 30 years, China has initiated extensive changes in S&T which have been directed at overcoming serious problems with research and innovation stemming from the policies and institutional designs of the Maoist period. These reforms have contributed to many of the positive developments and achievements of recent years, noted above. They have included aggressive increases in R&D funding, the stimulation of university research, the establishment of a National Natural Science Foundation (NSFC), the institutionalization of a competitive grants system, far-reaching changes in government research institutes, the introduction of a patent system, the encouragement of R&D in industrial enterprises and support for market forces in stimulating innovation.

And yet, many features of the pre-reform innovation system persist, including a strong faith in top-down, centrally directed research planning, a key policy role for a ministry of science and technology, the maintenance of a national academy of sciences as a major research performer, and a system for the governance of science which downplays the importance of decentralized professional mechanisms in favor of state control and direction. And, in many ways, past reforms have also engendered new problems. For the sake of our discussion here, the current challenges of reform can be grouped into four major categories:

1. Research Administration and Project Funding. As noted above, reforms over the past 30 years have included the introduction of a competitive grants system to replace, in large measure, the older system of block grants to institutions. However, while providing some benefits, the administration of the competitive grant system has also led to the introduction of many problems of research quality, misconduct, and waste. Administrative provisions limiting the size of grants, and allowable charges within grants (especially for personnel and overhead costs), have created incentives for investigators to increase the number of grants in their research portfolios, expand the number of graduate students to help with the expanded portfolio, and divert funds to augment low salaries. Research quality and graduate education often suffer as a result, with misconduct in the uses of grant funding always a possibility. The competitive grant system relies heavily on peer review, but a limited number of qualified reviewers and weak norms of confidentiality make the objectives of high quality, blind peer reviews difficult to achieve. This has the effect of enhancing the power of officials in science agencies whose favor is then sought by members of the research community who hope for positive decisions on grant proposals. In some cases, peer review mechanisms are used in situations where they are not appropriate.

2. User Orientation and Organizational Missions. A long-standing problem with the Chinese innovation system - a legacy of Soviet inspired institutions from the pre-reform era - has been the separation of research from production and from the users of new knowledge more generally (the so-called *liangzhang pi* problem). Although there have been some significant efforts at reform, the problem persists. The most advanced, and potentially transformational research occurs in the institutes of the Chinese Academy of Sciences and in the better universities but, despite much declarative support for the idea of research serving national needs, the task of doing so still involves formidable challenges of technology transfer from these research centers to users. This is true both for commercial technologies and for technologies supporting government missions and objectives. The main exceptions to this observation are high-priority national missions where resources and managerial attention can be concentrated on the achievement of the objective,

in keeping with the *liangdan yixing* tradition. Chinese industrial research, with the exception of a relatively few companies, remains underdeveloped and the research capabilities of mission oriented ministries and agencies (health, agriculture, meteorology, environmental protections, etc.) has not always matched the quality of work found in CAS and the elite universities.

3. National Priorities and Policy Coordination. As in other countries, national policymaking and coordination in China suffers from bureaucratic "stovepiping" which makes the achievement of national purpose - as something more than the outcome of bureaucratic struggles - quite difficult. In some ways, of course, China does take priority setting quite seriously, as illustrated by planning procedures for annual, five-year, and long-range plans which allow policymakers and members of the technical community to set national objectives and pursue individual and local interests. Plan i*mplementation*, however, becomes more difficult in the face of bureaucratic competition.

Efforts to develop broad policy coordination for science and technology through interagency exchanges have been focused on the work of the Science and Education Leading Small Group under the State Council, but its current status seems to have been diminished. Although, the Ministry of Finance has assumed a more active role in setting R&D budgets and developing mechanisms for financial accountability in recent years, its knowledge of the intricacies of the research system is limited, and China's long tradition of strong ministerial power has made the effective linking of policies, programs, and budgets difficult. Hence, the achievement of greater program effectiveness and financial accountability has been limited. The net result has often been a fragmentation of national effort (*jiulong zhishui, tiannu sanhua!*).

4. Evaluation. China has made major commitments over the course of the last 20 years to develop mechanisms for evaluating science and technology activities. But, the administration of the evaluation system has tended to valorize the *numbers* of SCI publications and, more recently, patent applications, such that individuals and institutions are rewarded by maximizing performance on these quantitative measures. The evaluation system, combined with the other problems of research administration noted above, is thought to lead to a great deal of rushed and derivative research and to contribute to the serious problems of scientific misconduct which characterize much of Chinese science. More generally, techniques such as peer review and various forms of project and program

evaluation often sit uncomfortably with Chinese cultural traditions associated with the importance of maintaining personal relationships (*guanxi)* and avoiding face losing candid criticisms.

Although the four problem areas noted above are, analytically, separable, they are in fact interconnected as a set of systemic problems. Major national priorities emerge from intense bureaucratic competition resulting from institutional failures at the top of the system. The interests of users get neglected in the course of bureaucratic competition in which the voices of users are not represented. Researchers seeking to advance their economic and career interests take their cues from these institutional arrangements and are driven less by concerns for quality work than for satisfying the requirements of the system. Central leaders who have normative commitments to scientific development, and who have backed these with substantial resources, lack experience with science and the mechanisms to monitor what goes on below them and, thus, lack the tools for enforcing accountability. Weak professional governance robs the evaluation system of a strong backbone.

Current Reform Initiatives.

The July, 2012 National Conference on Science and Innovation serves as a useful marker for the start of the latest round of reforms. At the Conference, Wen Jiabao bemoaned the performance of China's systems for research and innovation, and called for further reform. Two months later, in September, 2012, with the issuance of the important "Opinions on Deepening the Reform of the Science and Technology System and Speeding up the Building of a National Innovation System," the CCP Central Committee and the State Council brought a sharper focus to the need for further institutional reform. Clearly, as the second decade of the 21st century began, China's top political leaders were asking hard questions about the efficiency and effectiveness of all the money that was going into science and technology.

During 2014, these hard questions were being converted into a series of science and technology reform initiatives which by the end of the year were reflected in a series of reform policy documents addressing many of the problems noted above. These include a clarification of the legal foundation for reform, especially with regard to transparency in the administration of research funding and the conduct of research projects (*Guofa* 2014, no. 11). Project budgeting procedures were being improved by allowing for more rational salary and overhead allowances. New procedures were introduced to make the funding of research, and the results of research, more transparent.

Multiple government funding programs were being consolidated into five major funding streams: basic science support, support for major national projects (*da xiangmu*), funds for key national R&D programs, special technology innovation funds, and support for large facilities, research and innovation platforms, and human resource development. Progress was made in attacking some of the procedural difficulties that had developed in implementing Bayh-Dole type policies in China; through pilot programs introduced in the high tech parks in four cities (Beijing, Shanghai, Wuhan, and Hefei), research institutes and universities were given clearer rights to the benefits, use, and transferability (*san quan*) of the intellectual property they develop. To further stimulate the integration of research and technology with the economy, reforms were introduced to stimulate the growth of an S&T service industry (*keji fuwu chanye*) to include the strengthening of capabilities for the management and utilization of intellectual property.

In the area of reforming the evaluation system, new regulations were introduced to reduce the exposure of the research community to wasteful evaluation practices, thus reducing the time and effort needed to prepare for evaluations. More attention was to be given to qualitative factors in evaluation, instead of an overreliance on numbers of papers and patents, and a database of appropriate professionals to serve as peer reviewers was established. Meanwhile, the Chinese Academy of Sciences pushed ahead with its programs for the assessment of the work of its research institutes using international panels of scientists. The importance of building high-level science advisory mechanisms was recognized, and new regulations were introduced affecting the procedures for nominating and selecting academicians for CAS and the Chinese Academy of Engineering.

In an effort to further promote the development of a modern research management system, important reforms were introduced by CAS (discussed further below), and the Ministry of Education approved reform efforts at 47 universities aimed at the development of university charters, modern governance mechanisms, and budget management, including comprehensive reform measures at several leading universities affecting the introduction of new disciplines, student recruitment and human resource management.[1]

[1] For a useful summary of the 2014 reform initiatives, see the analysis provided by Li

Policy Mechanisms.

Not surprisingly, such systemwide reforms will also require changes in the national science and technology bureaucracy. While a number of these have yet to be announced, several changes can be noted. Importantly, a new approach to the inter-ministerial coordination problem was introduced with the establishment an "inter-ministerial joint conference system" (*bùjì liánxí huìyì zhìdù*) to coordinate and "unify" the government science and technology programs. Policy direction for this new inter-agency mechanism apparently will come from MOST and the Ministry of Finance in an attempt to establish a stronger organic link among policy, program, and budgeting. Along with the call for the establishment of a high-level strategic consulting/policy advisory mechanism with membership from industry as well as government and academia (*zhanlue zixun yu zonghe pingshen weiyuanhui*), these institutional arrangements for science and technology policy appear to be going in interesting new directions.

In several ways, these changes invite comparisons with US experience. The inter-ministerial joint conference system, for instance, is somewhat reminiscent of the US National Science and Technology Council (NSTC), an interagency body which coordinates the implementation of science policy within federal agencies.[2] Although the NSTC is nominally headed by the US President, and includes the Vice President as a member, its day to day direction is led by the Office of Science and Technology Policy (OSTP), whose Director also serves as the President's Science Advisor.

Xiaoxuan in "Kejì Tizhì Zòuxiang Shen Gaiqu," *Guangming Ribao*, January 9, 2015. At http://epaper.gmw.cn/gmrb/html/2015-01/09/nw.D110000gmrb_20150109_2-10.htm?from=groupmessage&isappinstalled=0.

[2] According to its website, "A primary objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in a broad array of areas spanning virtually all the mission areas of the executive branch. The Council prepares research and development strategies that are coordinated across Federal agencies to form investment packages aimed at accomplishing multiple national goals. The work of the NSTC is organized under five primary committees: Environment, Natural Resources and Sustainability; Homeland and National Security; Science, Technology, Engineering, and Math (STEM) Education; Science; and Technology. Each of these committees oversees subcommittees and working groups focused on different aspects of science and technology and working to coordinate across the federal government." At http://www.whitehouse.gov/administration/eop/ostp/nstc.

NSTC, thus, is part of the science and technology policy apparatus in the Executive Office of the President. That apparatus also includes the President's Council of Advisors on Science and Technology (PCAST), a body of distinguished scientists and engineers from universities and industry. OSTP coordinates with the Office of Management and Budget (OMB) in developing the President's budget for science and technology. As parts of the Executive Office of President, both OMB and OSTP are supra-departmental (or "supra-ministerial") agencies deriving power and authority from the Office of the President.

In China, with the increased role of the mission oriented ministries (Agriculture, Environment, Public Health, etc.) in supporting the nation's research, the initiation of the new Chinese inter-ministerial coordination mechanism would seem to be a sensible move, especially given the linkage to the budget process through the key role of the Ministry of Finance. The introduction of a new strategic consulting/advisory council also seems to be serving an important need, especially since it should include distinguished representatives from industry and the economy, as well as from academic institutions. Both new Chinese entities are reminiscent of NCST and PCAST, but the analogy to the US system has its limits.

It is not entirely clear, for instance, what the relationship would be between the new inter-ministerial mechanism (*bùjì liánxí huìyì zhìdù*) and the advisory council (*zhanlue zixun yu zonghe pingshen weiyuanhui*). In the absence of the functional equivalent in China of a president's science advisor and an OSTP, the underlying reporting and authority relations in the new system also remain somewhat unclear. This is especially true with regard to the resolution of conflicts, should they occur, in the inter-ministerial forum, given that all members seemingly would have the same ministerial level or rank. It is also not clear, to whom the advisory council should report; should it be to the inter-ministerial conference, or to some higher political authority? In these and other ways, the new Chinese approach to S&T policy arrangements differ somewhat from those of the US in spite of the fact that they seem to have similar purposes.

Reforming CAS.

The national reform program, discussed above, carries implications for a variety of research performers, including the Chinese Academy of Sciences, universities, government research institutes, and industry. Reforms in the Chinese Academy of Sciences serve as an interesting case of how the community of research performers might respond to the broader national reform environment.

The CAS reform, referred to in English as the "Pioneer (*shuaixian xingdong*) Initiative," has the potential to bring about the most radical changes in the Academy since the 1950s. It grows out of the policy instructions issued by President Xi Jingping during his July, 2013 visit to CAS, and the need to respond to the broader national S&T reform program discussed above. The initiative involves reorganizing CAS institutes into four major thematic categories, enhancing its educational missions, and through reforms in the academician (*yuanshi*) system, strengthening its policy advisory functions. These changes can be seen as the latest in a series of attempts to overcome long-standing problems of mission definition and management within CAS as it has had to face the significantly different national innovation system in the post-1978 era. But, in addition, the changing expectations from the new central political leadership, reflected in the new national reform program, have given the reform program a new urgency.

CAS, of course, had already experienced considerable change under the terms of the "Knowledge Innovation Program," (KIP). Under KIP, the Academy underwent a series of reforms from 1998 to 2010, and benefitted from the infusion of substantial funding intended to make it a more capable institution for meeting national needs. But, in spite of much progress in enhancing capabilities for research and innovation as a result of KIP, CAS missions and objectives remained somewhat uncertain.[3] And, rather like the national laboratories in the US, CAS and many of its institutes have yet to find the right institutional orientation for responding to the new innovation challenges of the 21st century. For instance, the US Department of Energy experiences problems in the relations between DOE headquarters and its labs, in the organization of headquarters, and especially in moving the technology developed in the labs to the market.[4] Such problems have been evident in CAS as well.

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3 Richard P. Suttmeier, Cong Cao, and Denis Fred Simon. "Knowledge Innovation" and the Chinese Academy of Sciences." *Science*. April 7, 2006. Vol. 312. no. 5770, pp. 58 - 59.

4. See, Matthew Stepp, Sean Pool, Nich Loris, and Jack Spencer. *Turning the Page: Reimagining the National Labs In the 21st Century Innovation Economy*. Joint report from The Information Technology and Innovation Foundation, The Center for American Progress, and The Heritage Foundation. June, 2013. At http://www2.itif.org/2013-turning-page-national-lab-innovation-economy.pdf.

The change in leadership occasioned by the appointment of scientist Bai Chunli to replace engineer Lu Yongxiang as CAS president, provided an opportunity for further changes. Although Bai introduced a number of policy changes at the outset of his presidency, those of the last two years have been the most consequential. They include, importantly, a strengthening of the Academy's educational activities (most notably, by the rapid development of the University of the Chinese Academy of Sciences in the Beijing suburbs and Shanghai Tech University), efforts to build a high quality think tank of relevance to the nation's policy needs, and an innovative effort to reorganize the Academy's 100+ institutes. As with the national reforms discussed above, we are still in the early stages of implementation, and how these initiatives will unfold remains to be seen. Nevertheless, some of the changes are already notable.

The reorganization of CAS institutes, seemingly, is an attempt to clarify Academy missions and devise management and policy strategies appropriate to the functions and capabilities of the various institutes.[5] According to the current plan, institutes would be reorganized into new entities falling into one of four main categories: centers of excellence, innovation "academies" (*chuangxin yuan*), platforms for large facilities, and centers for supporting national environmental and resource needs and those of local economies. In principle, this categorization is seemingly an imaginative approach which recognizes diverse capabilities and functions provided by the institutes and the need, therefore, to develop managerial strategies appropriate for the different missions and competencies.

For instance, the fundamental science capabilities of some institutes are at, or near, international levels and offer China opportunities to make world-class scientific contributions. Recognizing these as "centers of excellence," providing them with stable funding, and linking the research missions with elite education would seem to make a great deal of sense. Similarly, a number of institutes have strengths in upstream innovative activities in a diverse range of technologies without necessarily being at the forefront of basic science. The incorporation of these into "innovation academies," seemingly, is also a step towards rationalizing organizational arrangements in ways that are consistent with functions. The same

[5] See, Bai Chunli. "The Reform of Research Institutes: Which Way to Go?" Chinese Academy of Sciences, November 13, 2014. At http://www.cas.ac.cn/xw/zyxw/yw/201411/t20141117_4253641.shtml; Chinese Academy of Sciences. "Initial Procedures and Common Policies for the Classification of CAS Institutions," November 13, 2014. At http://www.cas.ac.cn/xw/zyxw/yw/201411/t20141113_4251558.shtml.

could be said for institutes characterized by large facilities, and those in the field sciences dealing with environmental and resource issues.

In spite of the appeals of this blueprint, though, several problems are likely to make the full implementation of these changes especially challenging, and illustrate, perhaps, some of the types of problems that the broader national S&T reform program will also face. First, while the attempts to bring better alignment between function and organization are understandable, many institutes are multi-functional and multi-mission, in part as a result of the policies of the Lu Yongxiang period and changes introduced during KIP. Thus, some institutes with strong basic research capabilities have also developed capabilities in applied research and development of relevance to technological innovation. Some of those housing large facilities are also leaders in promoting major technologies and might be classified as "innovation academies." How these institutes should be categorized constitutes a major challenge, and points to the possibility that established institutes will be broken up and the pieces reorganized or reassembled into the new entities. Such reorganization, though, will surely be disruptive, will introduce additional churn into the professional lives of researchers, and is likely to lead to considerable resistance and possible compromise of reform objectives.

This is especially true when we consider questions of funding, the legal status of the new organizations, and principles of personnel management. In the case of the centers of excellence, the idea seems to be to provide stable public funding and reducing the share of funding coming from competitive grants. Since some of the centers which have already been established are being incorporated into "colleges" (*kejiao runghe zhongxin)* at the new CAS University, one can imagine their affairs will be managed in a somewhat familiar academic mode.

Less clear are the other three categories, especially the "innovation academies." These, presumably, will face a more competitive funding environment, and it is not clear to what extent funding should be coming from government sources or from industry sources. Given the overall drift of national policy towards having market forces play a greater role in the innovation system, we would expect these new innovation-oriented organizations to have more intimate relations with users. At the same time, much of the R&D that would be performed is likely to be upstream, looking at longer-term national needs and priorities, and therefore, perhaps not always consistent with market expectations. Personnel policies for the "innovation academies" are also uncertain; would personnel, for instance, still have the status and benefits enjoyed now by CAS personnel, or would they face a more competitive and uncertain employment environment?

The ways in which such questions are approached and resolved within CAS are strongly influenced by broader national concerns for reforming the so-called "public service units" (*shiye danwei*), a broad category of institutions in Chinese law into which CAS, universities and most research institutes and educational institutions fall. Since the 1980s, China has sought to redefine the role of the *shiye danwei* in ways that would make them more efficient, contribute to the reduction of the size and scope of the state and, more generally, create an institutional environment suitable for a market economy.

As these *shiye danwei* reforms have affected research institutions, they have created complex challenges about the directions of institutional change. Should the organization targeted for reform remain part of the government administration? Should it (perhaps, in the case of the *chuangxin yuan*, for instance) become some sort of hybrid organizations having both government support and opportunities to participate in the market and generate contract income from industry? Should it become a fully not-for-profit service organization or, should it transition into a commercial enterprise, subject to market forces (*qiye hua*)?[6] Such questions point to the special difficulties China faces in defining the proper role of government in the innovation system, discussed further below.

Attempts to resolve such questions, in turn, involve a consideration of the disposition of assets, the governance structures in reformed institutions, budgeting and financial arrangements, and personnel policies, especially with regard to leadership, ranks, salaries, and the legal status of employment position.[7] These are all complicated and contentious issues that point to the difficulties of reforming the S&T system.

A Successful 21st Century Innovation System?

As noted above, in spite of the fact that China has seen a number of successes in the development of its science and technology in recent years, the innovation system has also been plagued by serious problems. Today's reform efforts have

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[6] Cf. Karla W. Simon. "Reform of China's Laws for NPOs - A Discussion of Issues Related to *Shiye Danwei* Reform." 2/2005 *ZChinR* 2005, at 71 (Journal of Chinese Law).

[7] Simon. "Reform of China's Laws for NPOs..."

clearly been directed at solving those problems. But, thinking ahead, are they also laying the foundation for a highly productive innovation system for 21st-century conditions?

As Dieter Ernst, and others, have recently noted, those conditions include an international environment characterized by increasing socio-technical complexity involving new science-based technologies, demanding market conditions, complex, globally dispersed business organizations practicing innovative business plans, and a variety of innovation policies from national governments, many of which defy international hamonization. Under these conditions, single companies, and even single nations, are often less able to generate competitive knowledge assets by themselves, with the result that we have seen the emergence of global innovation networks, as well as global production networks.[8]
This socio-technical complexity also begets new forms of uncertainty and, thus, new challenges for decision-makers. As Ernst observes,

"Uncertainty implies that it is always preferable to have built-in redundancy and freedom to choose among alternatives rather than seeking to impose from the top the 'one best way' of doing things..... It (uncertainty) *makes it difficult to predict possible outcomes of any particular policy measure, especially unexpected negative side effects, of which there is an almost endless variety..... and....it is next to impossible to predict the full consequences of interactions among the increasingly diverse population of ....domestic and international stakeholders."*[9]

Ernst goes on to note that therefore, "prioritization is no longer the exclusive role of the state planner." The role of government becomes less a matter of selecting "priority sectors, technologies and areas for public investment," and more one of removing regulatory constraints and providing incentives for the research and innovation activities of the market actors participating in global networks.[10]

Policymakers in the OECD countries are struggling to identify the right operational tools to respond to these challenges of complexity and uncertainty. In Europe, there is much discussion of "smart specialization," for instance, which seeks not

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[8] Dieter Ernst. "From Catching Up to Forging Ahead? China's Prospects in Semiconductors." East-West Center Working Papers, Innovation and Economic Growth Series, No.1, November, 2014. pp. 42 ff.

[9] Ernst. p. 44.

[10] Ernst. pp. 44-45.

only to provide broad "framework conditions" for an innovative environment, but also to encourage naturally occurring regional comparative advantages and specialized capabilities through a "light touch" of vertical government intervention.[11]

A recent report on the US innovation system, by contrast, takes a somewhat different approach. It argues that the best way to provide resilience in the face of unpredictability is to focus on three critical objectives: 1) maintaining "a talented and (globally) interconnected workforce," 2) "adequate and dependable resources," and 3) "world-class basic research in all major areas of science" to allow for the exploitation of discoveries in a variety of fields. In the words of the report, "A world-class basic research enterprise attracts scholars from around the world who in turn enhance excellence in research and create a self reinforcing cycle."[12]

The latest round of Chinese reforms, discussed here, are still in the early stages and the full course of their development remains unclear. But, as China pursues today's reforms, the resulting adjustments to its innovation system cannot ignore these 21st century realities and the challenges they offer. Hence, going forward, several key issues warrant particular attention. Some of these are shared with countries in the OECD, some are more distinctively Chinese.

The Role of Government. In one sense, the current discourse about science and technology reform in China is not unlike discussions in the OECD countries as they try to understand the proper role of government in a nation's science and technology system. As in the OECD, market failure issues associated with research and innovation, and the needs for supporting strategic technologies and basic research, are broad justifications for an important role for government. Still, in light of the changing nature of the 21st century innovation ecosystem, the determination of when and how government should intervene in the market, and how the government should organize itself to support research and innovation, require imaginative new thought and creative institutional design.

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[11] See, for instance, Dominique Foray and Xabier Goenaga. "The Goals of Smart Specialization." European Commission, JRC Scientific and Policy Reports, S3 Policy Brief Series, No. 01/2013, 2013.

[12] National Research Council, Committee on Assessing the Value of Research in Advancing National Goals. *Furthering America's Research Enterprise*. Washington, DC, The National Academies Press, 2014. pp. 2-3.

We see both of these questions on the Chinese reform agenda, but the background conditions in China differ from those of the OECD world. First, China has a long tradition of relations between intellectuals and the state in which knowledge is taken as serving, and being subordinate to, the state. Since 1949, this tradition has taken the form of having strong state direction of the entire science and technology system. Of course, as market forces have come to play a greater role, and as China has seen the rise of successful high-technology enterprises outside of the state system, assumptions about the primacy of the state have come to be questioned in recent years. This is especially true since the convening of the 18th Party Congress, and the emphasis placed on market reforms. Yet, the path dependency resulting from the tradition of state leadership is difficult to reverse; the long and difficult experience of attempting to refrom the *shiye danwei*, noted above, is but one illustration of the power path dependency.

Determining the proper role of government is also related to the stages of a country's economic development and the development of the science and technology capabilities, especially the R&D capabilities of industry. The strong government leadership, and mobilization of resources, which often characterizes successful "catch-up" phases of development, may be appropriate for early developmental stages. But, this approach may not be suitable for progressing "beyond catch-up" into areas of creative original scientific research and genuinely innovative technologies. As the experiences of other East Asian countries have demonstrated; many of the policies and institutions suitable for catch-up can become obstacles to moving successfully to a new phase of development.[13] An effective current reform strategy, therefore, must be designed with due attention to the nation's developmental stage, but this is no small task given the great variability in levels of development that remains in Chinese society.

A further complicating factor is the growing role of provincial and city governments in supporting science and technology in their jurisdictions. Given the large size of these sub-national government units, and the wealth some of them possess, it is likely that their role will increase. But, this raises interesting questions about the role of sub-national governments and the coordination between national and local level policy initiatives, especially since much of the recent support for technical entrepreneurship and institution-building for R&D in nominally non-governmental high-technology enterprises has come in the form of the strong

[13] Cf., Joseph Wong. *Betting on Biotech: Innovation and the Limits of Asia's Developmental State*. Ithaca and London. Cornell University Press, 2011.

underwriting provided by local governments.[14]

Government and Professionalization. An especially interesting aspect of the 2014 reform policies is the emphasis placed on "professionalization." As noted above, the reform program calls for an overall professionalization in the administration of government R&D, including both the allocation of funding and the further development of evaluation practices. Yet, it is not entirely clear what "professionalization" entails.

One of the things that characterizes effective modern governments is the infusion of professionalism into bureaucratic organizations. The modern public organization needs professional expertise of this sort, but fitting it in with traditional bureaucratic organization is not always easy. The importance of expertise in the modern bureaucracy has long been recognized, but that expertise would typically be nested in an organizational setting characterized by clear bureaucratic rules and regulations. Such expertise is not necessarily the same as professionalism, however. Normally, the definition of professionalism would include not only expertise but also principles of autonomy and fiduciary responsibility (i.e., the responsibility of the "trustee" that is less a function of bureaucratic or political control, but is rather based on values internalized through the training and socialization of the professional and enforced by self-governing professional organizations independent of the state).

Hence, not surprisingly, the modern public organization is characterized by considerable tension between demands for high levels of professional autonomy and the demands of bureaucratic responsibility and control. This is especially true with science and technology-related organizations where the demands for professional expertise is especially important. Because of this tension, we can see that some organizations - for instance, by altering bureaucratic regulations and changing the personnel management principles of the civil service to permit the employment and compensation of high-quality engineers and scientists - manage it well and are successful. Others don't manage the bureaucracy-professionalism

[14] For an interesting discussion of efforts align national local government research and innovation policies, see Di Guo, Yan Guo and Kun Jang. "Government Subsidized R&D and Innovation Outputs: An Empirical Analysis of China's Innofund Program." Stanford University Center for International Development, Working Paper No. 494, February, 2014. At http://scid.stanford.edu/publicationsprofile/2743.

tension well and develop serious problems.[15]

Since Chinese political principles have left little room for a genuine realm, or sphere, of professional life independent of the state, it remains to be seen what sorts of institutional innovations emerge from the reform program that would allow for a significant professional role in research administration. Will that role simply be an extension of state power in a new guise of "enhanced expertise," or will it reflect opportunities for the exercise of genuine professional autonomy? As Don K. Price has pointed out in his classic study of science and government, there is always a significant challenge in finding the right balance between professional autonomy and government accountability.[16] The conditions for research and innovation of the 21st century add new dimensions to this challenge.

The Internationalization of liangzhang pi. Clearly, one of the driving forces behind current reform efforts is to come up with effective new ways of overcoming the long-standing problem of research being separated from production or, from users more generally. This problem has deep roots going back to the pre-reform era, and in spite of a series of reforms beginning in the 1980s, aspects of the problem remain unsolved. China has changed remarkably since the initiation of the reform era, but, again, path dependencies characterized by the organizational separation of research and production are often difficult to overcome, and this is the case with the *liangzhang pi* problem.

Historically, the *liangzhang pi* problem has involved a misalignment of interests and incentives between organizations in the research system, and industrial producers. While economic reforms, as well as S&T reforms, over the past 30 years have made progress in realigning these interests and incentives, it is clear that more needs to be done. The various measures to stimulate innovative activities in industry through positive (e.g. special subsidies) and negative (e.g. reduction of policy preferences in state owned enterprises) incentives have clearly had positive effects, as have policies to encourage research institutes and universities to be more

[15] For a history of the bureaucratic-professionalism tension in post-1949 China, see Richard p. Suttmeier. *Research and Revolution: Science Policy and Societal Change in China*. Lexington, MA, Lexington Books, 1974

[16] For a classic statement of this problem, see Don K. Price. *The Scientific Estate*. Cambridge, MA, Harvard University Press, 1965. As the title suggests, Price's analysis is grounded in Western history and deals principally with the US. Yet, his concerns for "the spectrum of truth to power" resonates with current reform considerations in China.

engaged in the marketplace. The overall strengthening of the IPR regime has also had positive consequences for reducing the research to production problem, and new measures such as the *san quan* regulations, are expected to facilitate technology transfers from the leading centers of research.

While domestic reform policies over the years have impacted the path dependencies associated with *liangzhang pi*, the realities of global production and innovation networks may have played a greater role. The Chinese research system is no longer focused solely on technology transfer to domestic firms and, of course, Chinese industrial enterprises are acquiring technology from many sources, not the least of which are international sources. Thus, questions of international cooperation, in relation to national interests, constitute a prominent background condition for the whole range of science and technology reforms.

China has benefitted enormously from its "open-door" (*kai fang*) policies, including those which have led to expanded international cooperation in science and technology. It is difficult to imagine turning back from such international exposure, and today's policy statements all call for expanding international cooperation. On the other hand, Chinese industrial and technology policies have often shown strong techno-nationalist tendencies, and elements of cultural nationalism are evident in scientific research as well. The larger national reform agenda of the current government, especially with regard to information policies, also shows the influence of a growing nationalism. Such tendencies have raised concerns among China's international partners and work against the building of the trust needed for long term, sustainable collaborations. Whether reforms in science and technology are likely to push China's research and innovation system in the direction of greater techno-nationalism and/or scientific nationalism, remains to be seen. In a world characterized by the globalization of research and innovation, a nationalistic turn in science and technology policy deriving from reforms, seemingly would be ill-advised; it remains to seen, however, whether the broader political environment will push the reform program in that direction.

In spite of a variety of farsighted policies to exploit opportunities in the international environment for scientific and technological progress, China is still in the early stages of a genuine internationalization of its research and innovation systems. Increasing R&D expenditures to world leading levels is not enough if China is to become a global leader in research and innovation and, thus, a magnet for talent and investment in leading areas of science and technology. In a world of globalized research and innovation, a key question that should be near the center of the reform agenda is whether the reforms will make accomplished scientists and engineers from other countries feel comfortable in making careers in Chinese institutions?

Conclusion.

The various reform efforts discussed above have important implications for the emergence of China as a science and technology "superpower." On one hand, one could argue that the changes introduced during the past year will better align the institutions of China's national innovation system with R&D spending increases and, thus, ensure that the funding that is being pumped into research will better serve China's aspirations for scientific distinction and technological leadership. But these reform activities also introduce major uncertainties into the research environment, uncertainties that are also exacerbated by the current anti-corruption drive which affects science and technology-related organizations as well as many other sectors of Chinese society. Chinese scientists and engineers are therefore facing an environment characterized by significant additional administrative unpredictability which affects R&D routines, professional incentives and career paths, and adds considerable uncertainty to the broader science and technology policy environment. It remains to be seen whether organizational and administrative uncertainties hold back progress, or whether good research and development can still occur in the face of widespread organizational churn?

While Chinese reform leaders seem to recognize the disruptive potential of change, and have therefore called for more gradual, multi-year implementation of some of the reforms, the fact remains that the longer-term consequences of administrative churn are largely unknown. For instance, as noted above, China's current funding system has fostered a hyper-competitive search for research grants which has often resulted in support of projects with short time horizons, and to wasteful duplication of expenditures in support of "hot" topics. While the reforms are intended to overcome such outcomes, one can well imagine that churn-induced uncertainty would nevertheless increase incentives for short-term opportunistic behavior from the research community at the expense of well conceived research and innovation programs requiring sustained efforts over the longer-term.

The current reform initiatives suggest that China is struggling with a legacy of policies and institutions that have led to a number of successes but which now impede movement toward the type of innovative society China hopes to create in the 21st century. As we have seen, defining the proper role of government in the nation's research and innovation systems continues to be a key challenge. As noted, China is not alone in confronting this challenge, and China's approach to confronting it will certainly be of interest to other countries.

That said, a preliminary assessment of the direction of the reforms would suggest that the solution to this challenge is not quite yet in hand. In large measure, this is because changes in the science and technology system are ultimately wrapped up with larger, difficult questions of economic and political reform. An especially apt illustration of the importance of these larger questions is the development of a successful national retirement system. A critical problem limiting the effectiveness of the innovation system, for instance, has been the low levels of mobility of technical personnel moving among research institutes, universities and industry, a problem deeply rooted in the absence of a system which would allow retirement benefits to move with the individual. Recent reforms in the retirement system to facilitate the portability of benefits, though not part of the S&T reforms, may have more benefits for the national innovation system than some of the S&T reforms themselves!

The emphasis placed on the role of market forces since the convening of the 18th Party Congress suggests that the current leadership is serious in reducing many aspects of the state's role in managing or administering the economy, and the S&T reform policy initiatives of 2014, reflect this preference. But, as the experiences in other countries illustrate, the role of government is often critical for maintaining and advancing a nation's capabilities for research excellence and technological innovation, and can therefor elicit strong action from political leaders, as we have seen with the current Chinese government. The performance of an effective government role, however, requires talented and farsighted individuals of integrity who are able to rise above parochial interests to help formulate and guide a broader national strategy. The challenges of this role have only become more difficult in light of the socio-technical complexities of the early 21st century. Science and technology reforms in China are occurring in the face of these complexities, but also in the face of deep and widespread anti-corruption initiatives from which science and technology are not immune. Such circumstances again point to the difficulties of defining a proper role for government at this point in time and, thus, predicting the likely success or failure of the reform initiatives.