The Discourse on China as Science and Technology Superpower: Assessing the Arguments

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In recent years exciting changes in China's scientific and technological development experience have attracted considerable international attention. They have led some observers to predict that China is a rising science and technology superpower. Others remain skeptical about China's prospects of reaching superpower status anytime soon. In this paper I explore the arguments advanced to support these different positions and attempt to assess their worth. First, though, let us consider what the concept of "S&T superpower" might mean.

There are various ways "science and technology superpower" could be defined. Here I employ several approaches. First, reference is made to statistical indicators of R&D input and output - superpower status is determined by benchmarking against the world's leaders on these quantitative metrics. Second, the quantitative achievements reflected in input and output data need to be subject to some form of qualitative assessment; superpowers are recognized for the quality of their work as well as for its quantitative dimensions. While Nobel prizes may not be a totally adequate indicator of superpower status, superpowers typically produce scientists who are competitive for Nobels. Third, it is useful to consider a country's capacity for large complex technological projects, including those relating to national defense, which few countries can match. Fourth, superpowers have comprehensive capabilities across most fields of science and technology. Fifth, superpowers have "vertical" depth - modern science and technology are not the activities of a relatively small elite but instead permeate society. This latter point implies a knowledge based economy, a certain congeniality between science and a nation's culture, and an effective integration of the spirit of science in the nation's decision making. Finally, superpowers are places where others want to come and learn, whether it be in universities or corporate or government research institutes.

Characterizing China's potential for S&T superpower status poses a special challenge because of its size and diversity. As a recent report from the OECD puts it, "On any measure, absolute numbers and per capita figures tell two different stories about China's national innovation system, both of which are true. Moreover, national averages can be particularly misleading because the geographical concentration of innovative activities is more pronounced in China than in almost any OECD country........several Chinese provinces or even municipalities are larger R&D performers than several OECD countries."[1]

The Rising S&T Superpower Case.

One of the striking features of today's science and technology trends in China is the high level of commitment to science and technology by the political elite and the enthusiasm for science and technology found in society more generally. Indeed, this elite commitment and popular enthusiasm are used by those making the positive interpretation in the superpower debate.[2] To understand the strength of these sentiments, it is useful to reflect briefly on China's modern quest for scientific and technological development.

It was, after all, the technological superiority of Western powers in the 19th century (and Japan by the end of the century) which contributed so significantly to the national humiliations which began at that time. National leaders, from the 1920s onward, thus embraced the idea that a modernized China of "wealth and power" would require the development of modern science and industry. However, for most of the 20th century war, revolution, and political extremism frustrated attempts to achieve science-based modernization. Viewed against this more than 100 years of history, the last 3 decades, from 1978 to 2008, have been, in general, "the best of times." Political stability, economic growth, successful institutional reforms, and productive engagement with international society have permitted the rapid progress in scientific and technological

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[1]OECD. *China*. OECD Reviews of Innovation Policy. Paris, 2008. Pp. 46, 50 (hereafter, OECD).

[2] As one informed foreign observer put it, the enthusiasm for science and technology in Chinese society today is reminiscent of the excitement in the US in the early days of the space program. See, Christopher Thomas. "China's Invent-It-Here Syndrome." *Forbes.com*. December 31, 2007.

development which proved elusive for much of the previous 100 years. Under these conditions, political elites have sought to provide the conditions which might make the achievement of superpower status plausible.

The first of these conditions, of course, is financial support. China's gross expenditures on research and development (GERD)/GDP has risen rapidly over the past decade from 0.6% in 1995 to 1.42% in 2006 (a figure which puts China ahead of Russia, Italy, Brazil and India, but behind most other OECD countries). The OECD estimates that China's GERD, at least in purchasing power parity (PPP) terms, is now third in the world behind the acknowledged S&T "superpowers" - the US, and Japan. According to Chinese statistical categories, roughly 70% of GERD now comes from the business sector (by source of funds and by performer of R&D), a distribution typical of the leading OECD countries and, arguably, a sign of significant R&D penetration into the economy. China's new "Medium to Long-term Plan" (MLP) calls for the GERD/GDP to increase to 2.5% by the year 2020, a target which, if achieved, would certainly put China in the superpower category, at least in expenditures.

A second consideration is the cultivation of human resources and the support of science education at various levels. Supporting the superpower thesis, of course, is the apparent wealth of talent in China. In 2006, there was an R&D workforce of some 1.5 million, 1.2 million of whom were scientists and engineers, and there were more than 8 million students studying science, engineering, agriculture, and medicine in Chinese universities.[3] In 2006, China awarded some 19,371 doctorates in science and engineering placing it third after the US and Russia, but with a trend line which will put it in first place in the very near future.[4] In addition, China benefits from its "science diaspora" and the international "brain circulation" which brings scientists working in China into active contact with ethnic Chinese colleagues working in some of the world's leading laboratories and high-technology firms. The result of these trends has been the transformation of the Chinese technical community into one that is younger, more achievement orientated, better compensated, increasingly productive, and much more

[3] Ministry of Science and Technology. Chinese Science and Technology Statistics, 2007 Data Book. Beijing, 2008.

[4] *Science and Technology Statistical Yearbook*

cosmopolitan and in tune with international trends than ever before.

Elite commitment is also much in evidence in the reform and revitalization of institutions for R&D. Hundreds of Soviet inspired government research institutes have been reorganized into, or merged with, market oriented industrial enterprises, thus strengthening R&D in the business sector. Hundreds more institutes in noncommercial fields have been subject to other reforms. The Chinese Academy of Sciences has been significantly strengthened and reoriented as a result of the well-funded "Knowledge Innovation Program" (KIP). Chinese universities have become important centers of research and programs have been introduced to bring China's leading universities up to world-class status. A policy environment has been created to encourage multinational corporations to establish R&D activities in China, with the number of such facilities now estimated to be more than 1100. The major commitments to R&D in China by major MNCs reinforces China's role as an increasingly important "node of innovation" in a globalized network of research and innovation.

A final measure of elite commitment is seen in the introduction of the MLP in 2006, a plan which might be viewed as a manifesto in support of S&T superpower status. In addition to the GERD/GDP target noted above, the plan calls for major national science and engineering projects in areas of national needs and in basic research, and more generally calls for China to become an "innovation oriented society" by the year 2020. It is expected that by that time China will have reduced its dependence on foreign technology significantly, will have become a leader in cited professional publications in science and engineering, will have become one of the top five leaders in patenting, and a major force in the setting of technical standards.

The discussion above focuses on the "inputs" supporting scientific and technological development. In each case, the trajectory is upward and impressive, supporting movement towards the superpower status. "Output" indicators have also been used by the superpower advocates to support their case. These would include, in the first instance, a variety of impressive technological achievements, the most spectacular of which being those associated with the space program. While the Chinese space program may not yet match the achievements of the US and Russian "space superpowers," it nevertheless indicates an impressive ability to master a number of sophisticated technologies and integrate them into complex systems. Other indicators include a rapid increase in patenting activities (China now ranks 4th in the world in invention patents granted) and China's emergence as an important contributor to the world's scientific literature (China ranks 5th in SCI indexed papers, but 2nd when EI and ISTP papers are included).[5] China's emergence as a leader in high-technology exports, likewise, points to movement towards superpower status, and its domestic market and extensive IT penetration suggests that there are powerful "market pull" factors which will propel domestic innovation.

In short, those advancing the argument that China is a rising science and technology superpower certainly have evidence to support their claims. In terms of both input and output measures, as well as in the measures of institutional change, the trend lines are impressive. The superpower argument, however, must confront a variety of other evidence pointing to vulnerabilities and lags in development which make the superpower argument somewhat less compelling. Let us consider some of these.

Superpower Skeptics.[6]

The skeptical reaction to the superpower thesis often begins by raising questions of quality, especially in research and in education. For instance, with regard to the "quality" of expenditures, the skeptic would argue, "Yes, Chinese research is in fact increasingly well-funded, but is the money being spent wisely?" China has invested heavily in large science facilities in recent years, for instance, but it is not entirely clear that they are all being used effectively by the technical community. Much of the national R&D expenditure effort is structured by large, bureaucratically driven, top-down national programs, the results of which in many cases have not held up well to careful evaluation and international comparisons. The

[5] In a recent paper Ronald N. Kostoff has pointed to the fact that the SCI index has a large biomedical component and thus tends to amplify the standing of countries with strengths in biomedical sciences. By implication, China with its relative strengths and physical sciences, should score higher in international comparisons if we control for biomedicine. Ronald N. Kostoff. "Comparison of China/USA Science and Technology Performance." Unpublished paper, The MITRE Corporation, 2008.

[6] The OECD report, cited above, offers one of the more thoughtful and balanced presentations of the skeptical view.

national project system is seen as being highly politicized, overly centralized, and lacking in coordination and cross communication. The strong emphasis that has been placed on publication and patenting as success indicators have led to quantitative expansions of these outputs but with disappointing quality, argue the skeptics. The high profile cases of scientific misconduct which have been reported in recent years may be indicative of a deeper problem of "soft corruption" in project selection and misuse of research funding.

Quality concerns in the area of human resources also demand attention.[7] For all the investments and progress made in higher education, reports persist of the perpetuation of a pedagogy emphasizing examinations and rote learning, inattention to serious, responsible teaching, and the treatment of graduate students as exploitable labor rather than human resources to be cultivated. As a result, in spite of having a numerically large technical community, the quest to secure high-quality science and engineering manpower from that community is a major challenge for universities, institutes of the Chinese Academy of Sciences, Chinese companies, and MNCs alike.

The quality problems inevitably call attention to realities in the research environment which work against quality improvements. Commercial pressures, for instance, have been cited as a problem for the building of a high-quality university-based research tradition. As suggested above, bureaucratic influences are strong throughout the system with the result that funding mechanisms may not always identify and select the best science. Likewise, evaluation pressures are thought to push members of the research community to satisfy bureaucratically set success indicators rather than achieving results of scientific significance. Perverse incentives are thus encouraged in the technical community - the funding system, which results in a series of relatively abundant smaller grants, makes the pursuit of new grants imperative, thus introducing mercenary considerations which often seem to trump considerations of quality science. The relative weakness of autonomous professional societies to counterbalance bureaucratic influences and foster a healthy culture of science may also work against progress in solving the

[7] Thus, while the absolute numbers of scientists and engineers in R&D is impressive, the production of professional papers and patents on a per capita basis lags behind OECD countries. OECD. p. 53.

quality problems.

These issues associated with the research environment thus produce a degree of anguish in Chinese thinking about progress toward superpower status. Chinese scientists can win Nobel prizes while working in foreign research environments, but haven't yet done so from a base in China. Chinese scientists and engineers have produced significant innovations in the laboratories of multinational corporations, both those in China and those abroad, but important innovations from Chinese laboratories have, in general, failed to appear. "Smart scientists, bad system," argue the superpower skeptics.

The superpower skeptics also point to problems in the broader societal environment which work against innovations of significance. These include an IPR regime which does not effectively protect and reward innovators and a system of finance, including an underdeveloped venture capital industry, which is insensitive to the need for strategic financial interventions in support of innovative possibilities. Some of these problems can be traced back to the persistence of overly bureaucratized institutions, but the skeptics also call attention to labor abundance in the economy and the development of a culture of low-cost production which makes the risk of engaging in technological innovation unattractive. Thus, for both economic and organizational reasons, long-standing gaps between the research community and commercialization have yet to be overcome, with the result that the market for the products of research remains underdeveloped and feedbacks from the economy to the research sector, articulating commercial opportunities, are weak.

Finally, in the area of large complex projects, the skeptics would argue that in spite of the impressive achievements of the space program, China is still a long way from having indigenous capacity for large complex projects. It will still be heavily reliant on imported technology for these projects (eg., aircraft, high speed rail) and cannot hope to match the superpowers anytime soon. Even in the area of national defense, where expenditures are rising rapidly and performance is improving, the gaps with the US remain large with the result that science and technology in support of national defense must be targeted and cannot attempt comprehensive improvement. As Tai Ming Cheung has argued, the defense S&T budget remains a small proportion of that of the US and, "This huge gap in funding strongly suggests that any Chinese broad-based leapfrogging efforts will fall far short of reaching the technological standards enjoyed by the US and its Western allies..... A more sustainable strategy is the concentration of limited resources in a select number of areas where chances of success in narrowing technological gaps are greatest. These pockets of technological excellence include portions of the dual use information and communications technology, dual use sectors and elements of the missile, aviation, space and shipbuilding industries."[8]

Just as the supporters of the rising superpower thesis can muster considerable evidence to support their claims, so too can the skeptics. Thus, as of this writing, we are still left with the question, "Is the glass half full or half empty?" "Filling the glass" in support of movement toward superpower status may thus be contingent on the way a number of critical challenges are handled. Let us review of the main ones briefly.

Technology Policy. China faces a fundamental challenge with regard to how to craft a technology policy which both allows it to strengthen its indigenous technological base while also benefitting from global technology flows. China has benefitted greatly from participation in global production networks and yet it has become dissatisfied with the relative gains it receives from participation. This is largely due to the fact that control over intellectual property, and technical standards embodying IP, give multinational corporations control over the higher value components of the value chain. China thus seeks to move up the value chain with the development of its own proprietary technology and technical standards. In doing so, however, it runs the risk of engaging in ill advised government technology development projects which push Chinese producers to support such projects, even when it is against their economic self-interest to do so. Chinese industrial enterprises have often prospered by introducing foreign technology while largely ignoring the possibilities for indigenous innovation. For Chinese techno-nationalists, this suggests a level of technological dependency which is unhealthy and which requires government action to remedy. Thus, central challenges to technology policy become ones of determining the scope and style of government intervention in the economy. As the

[8] Tai Ming Cheung. "The Remaking of the Chinese Defense Industry And the Rise of the Dual Use Economy." Testimony Before the US China Economic and Security Review Commission. July 13, 2007.

OECD puts it, “The government still faces the challenge of appropriately balancing the new market-based approaches to innovation and direct government support for a national R&D programs.”[9]

The problem of finding the right role for government is complicated by the generally weak capacity of Chinese industrial enterprises for innovation. As noted above, the business sector in aggregate statistical terms, has emerged as a dominant source of R&D spending and performance. Nevertheless, there is considerable evidence that an “enterprise problem” persists; R&D expenditures as a share of sales, or value added, remain quite low, even in high technology industries, and Chinese companies lack the personnel and organizational arrangements to become the true centers of the national innovation system, as called for by policy. This raises interesting questions as to whether the technological needs of Chinese companies can be effectively addressed by outsourcing to Chinese universities and government research institutes, or perhaps to research centers abroad.[10]

Science and Social Needs. The MLP gives considerable attention to the need for the technical community to serve social needs and to support the provision of public, or quasi public, goods in such areas as energy, health, agriculture, environment, disaster management, and in food, drug, and industrial safety. Research funding is now flowing to support such purposes, but this fact does not fully address the question of innovation challenges in public goods provision. Much of China’s reform experience with research and innovation over the past 20 years has been focused on market oriented transfers of research to production. Less attention has been paid to the transfer mechanisms in support of social needs. While many of the government agencies charged with providing public goods have their own R&D activities, most are not noted for being cutting edge. Instead, the kinds of high-quality scientific work that would enable science to more effectively serve social needs is more likely to be found in the Chinese Academy of Sciences and universities, but the linkages between advanced research and users are often not

[9] OECD. p. 72.

[10] The OECD reports that in 2006, 37% of the R&D performed by Chinese universities was funded by business enterprises. OECD. p. 64.

well developed. A related issue is the ability to use science effectively in building the kinds of strong regulatory systems that are called for in light of the safety and health problems which have plagued China in recent years.

Basic Science. Superpower status is likely to elude China without its confronting the challenge of building a strong tradition of basic research. Whereas OECD countries are spending 10 to 20% of national R&D on basic research, the figure in China hovers around 5-6%. In addition to the need to increase funding for basic research there is also a need to promote its creativity. Foreign observers and Chinese alike often bemoan the fact that Chinese research seems to be more derivative than original, a problem which seems to be related to both the culture of research in China and the institutional environment. Further complicating the basic research challenge is the problem of maintaining scientific integrity in an environment which often rewards opportunism.

The Globalization of Research and Innovation. The globalization of research and innovation poses many challenges for national governments. As noted above, China's technology policy has to navigate between the appeals of participating in global production networks and building up *national* technological capabilities. This tension between what might be called techno-nationalism and techno-globalism is evident in other realms as well. For instance, the work of China's better research institutes and universities is often of greater interest to multinational corporations than to Chinese industry which raises the question of whether foreign companies become the beneficiaries of publicly supported research in China, rather than some Chinese entities. But, perhaps, Chinese society as a whole benefits from the development and utilization of ideas that originate in China, even if that development is performed by foreign entities. As we see all over the world, the challenge of discerning what is *national* interest in an age of globalization is not a simple one. This is true even in areas of national security, where the definition of national interest seemingly is more straightforward. China's eligibility for superpower status will require that it find the right balance between national interest and global engagement in its interactions with MNCs, in its defense and national security programs, and in its approach to international scientific cooperation.

Governance. As in other countries, when national expenditures on research and development increased noticeably, concerns inevitably arise from national political leaders and budget authorities as to whether the money is being spent wisely. In recent years, this has been the case in China, as well, as concerns for the accountability of the research system increase.[11] The accountability question, in turn, calls attention to more general issues of governance affecting research and innovation in China. These would include questions of effective national coordination of research activities (including coordination between central and local authorities now that the latter accounts for some 40% of the government share of the nation's R&D funding),[12] and ensuring that ministries and agencies with responsibilities for meeting national needs are staffed and organized in ways that will enable them to use modern science effectively to support their missions. And, as suggested above, China faces the challenge of building science-based regulatory agencies which can control technological risks and ensure the sustained development of a market economy. In each of these areas, there is still much progress to be made.

Science and Society.

By many measures, China's progress in science and technology over the past 25 years is impressive. China is a country where political leaders seem to pay more attention to S&T policy questions, and have more training in science and engineering, than do the political elites of most other nations, and where science and technology are celebrated in the mass media to an extent seldom found elsewhere. At the same time, it is possible to view segments of Chinese society as resisting science - as body of knowledge, as method, and as attitude - to a remarkable degree. As a result, some observers - both in China and abroad - have come to view China's scientific and technological achievements of the recent decades as a thin veneer of modernity which covers up a national culture which variously could be called pre-scientific, anti-scientific, or a-scientific. While this picture is undoubtedly overblown, it does nevertheless raise questions about the

[11] According to the OECD, "....the current government system may not be well suited to carry out the mission set out by the S&T Strategic Plan (2006-20) (i.e., MLP) owing to the lack of interagency coordination to ensure the consistency and coherence of various policies, to improve systemic efficiency and to optimize resource allocation." p. 77.

[12] OECD. p. 78.

nature and status of science in contemporary China, and the ways in which the prospects for superpower standing is affected by the status and social relations of science.

Much of the domestic and international interest in Chinese scientific and technological development, alluded to at the outset, has been focused on what might be called China's "science for development" agenda - the acquisition of national technological capabilities and the increasing role which domestic R&D might play in acquiring them. Less attention has been given to important issues relating to attitudes towards - and priorities for - basic science, the uses of science in governmental decision making, the ways in which the values and culture of science affect (and are affected by) society, the ways in which society and the state approach the definition and assessment of risks and hazards, and perhaps most importantly, the ways in which scientific standards of truth acquire culturally sanctioned authority. These issues are all part of what might be called a "science in society" agenda, analytically separable from, but in actuality related to, science for development.[13]

Concerns for these "science in society" issues in China also have their roots in early 20th century debates about modernization and the nature of modernity which involved not only the role of science in creating a strong and prosperous China (the "science for development" agenda) but which also involved searching questions about the relationships between Chinese culture and modern science. After 1949, the issues of the "science in society" agenda were effectively removed from active consideration by the imposition of a political formula which purported to offer a resolution of them. As the terms of this political formula increasingly came to be questioned in the reform era, "science in society" questions generally were overlooked at the policy level in the excitement over the pursuit of the science for development agenda inherent in

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[13] The distinction between "science in society" and "science for development" agendas is inspired by the recent work of Drori, Meyer, et.al. who distinguish between a "science for development *discourse*" and what they refer to as a "*science and human rights discourse*" which explores the ways in which scientific development affects political and social rights. On the relationships between the two, they note that "Science, adopted as a narrow instrument, yet working as a cultural framework and a secularized source of legitimacy and authority, affects the foundations of social life in a much broader sense than is recognized in general, and in policy discussions." G. Drori, J. W. Meyer, et al. (2003). *Science in the Modern World Polity*. Stanford, Stanford University Press. p. 279.

the “four modernizations” program. Gradually, however, “science in society” questions began to emerge in the face of rapid economic development and social change as the social costs of modernization became more apparent. This has been especially true with regard to the quality of government decision making on technologically and/or environmentally complex problems, problems of environmental policy and matters of health and safety, and with the problems of public understanding of science.

The SARS outbreak of 2003 brought a much sharper focus to “science in society” concerns, as have more recent concerns over food and drug safety. These developments have called attention to problems in government decision making, particularly with regard to science as an independent source of authority for decisions. They also suggests that in spite of considerable progress with the “science for development” agenda, science as a strong cultural force, especially for understanding and assessing risks, is not deeply rooted in contemporary Chinese society. The SARS case also raised questions about the priorities of China’s science policies and the purposes of national research programs. In short, the health and safety problems which have come to light in recent years suggest that “science in society” questions can no longer be ignored, and that the “science for development” agenda is at some point critically dependent on how “science in society” issues are managed. While superpower status can be understood in terms of measurable inputs and outputs, the degree to which a comprehensive set of research and innovation capabilities exists in a society, and in terms of a capacity for complex technological achievements, it may also ultimately depend on the ways in which science resides in society and interacts with culture.

“The network is the critical resource”[14] - From Superpower to Supernode?

As modern scientific and technological capabilities diffuse to new regions of the world, and as international cooperation in research and innovation increases, the concept of a “science and technology superpower” needs rethinking.[15] Implicit in the superpower concept is the notion

[14] Caroline S. Wagner. *The New Invisible College*. Washington. Brookings Institution Press. 2008. p. 68.

[15] J. Rogers Hollingsworth, Carl H. Muller, and Ellen Jane Hollingsworth. “China: The End of the Science Superpowers.” *Nature* 454 (24 July, 2008). Pp. 412-413

of a concentration of capabilities possessed by a *national* entity, a mode of thought derived from 20th-century experience. While scientific and technological development clearly still remains a national project for many countries, the early 21st century is also exhibiting trends towards a *denationalization* of science as the international mobility of research personnel increases, as research funding flows across national borders, and as multinational research projects seek to exploit talents around the world. These trends have reinforced the image of research and innovation as globally networked activities in which multiple "national" nodes of activities are linked together in interdependent ways.[16] While certain nodes are clearly more significant in the network than others, network dynamics make it unlikely that any one node will have the autonomy and dominance one might expect of a "superpower."

An important policy imperative follows once the network concept is accepted. In a world of *national* science and technology, the policy orientation is focused on building indigenous R&D capabilities. While such a policy orientation persists in a networked world, it also becomes imperative for policy to focus on exploiting resources from the network, including the network externalities resulting from multiple interactions. Leadership in a networked world can be defined as becoming a major node in the network, or perhaps a "supernode." Measuring this success, in turn, will probably require different metrics than those used to measure progress toward superpower status in a world of national science and technology.

There is an undeniable dynamism today in China's science and technology circles, and trends towards world-class scientific and technological capabilities are certainly discernible. However, China's political and academic leaders understand that the achievement of world-class capabilities is no easy task and that the 2020 targets of the MLP is unlikely to yield the comprehensive capabilities which we would expect from a superpower. It remains to be seen, however, whether the superpower discourse within China remains the dominant one, as it has been. Might the idiom shift to the language of networks and the objective to one of becoming a "supernode?" In interesting ways - through its open door policies, its capacity for policy learning from foreign experience, its strategies for international scientific and technological

[16] Cf., Wagner. *The New Invisible College*.

cooperation, and especially through its “scientific diaspora” - China is especially well equipped to become a leading presence - if not a “supernode” - in 21st-century global networks of research and innovation. While some among China’s more techno-nationalist elites might still embrace the idea of national scientific and technological capabilities as serving superpower aspirations, others are clearly coming to the belief that “the network is the critical resource.”

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