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CHINESE SCIENCE POLICY AT A CROSSROADS

US efforts to decouple from China's innovation system could end up making China more independent and more capable.

The sharp deterioration of United States-China relations over the past 18 months has raised a series of new challenges for Chinese scientific development. What started out as trade friction has evolved into a complex conflict, one in which Chinese strategies for technological development figure prominently. US concerns over Chinese scientific and technological progress, seen by policy-makers across the political spectrum as increasingly threatening, have led to a notable tightening of US export controls and foreign investment regulations, stricter controls over visas for Chinese scientists and engineers, and more active investigations into the behavior of ethnic Chinese scientists working in US universities and companies. The once flourishing bilateral relationships in science and technology—in universities, industry, and government—are now clouded by growing concerns in the United States and China over national security and the protection of intellectual property.

Increasingly, we hear talk of a technology war and a possible decoupling of the US and Chinese innovation systems. Though arguments for decoupling are often traced back to Washington, decoupling impulses exist in China as well. A number of developments suggest that Chinese leaders are doing their part to promote this decoupling: Chinese internet policies contribute to the bifurcation of cyberspace; information control policies are an increasingly serious irritant for foreign investors; and restrictions on data-sharing, long a problem in international scientific cooperation, are on the rise. Chinese industrial policies are attempting to promote the international adoption of Chinese-developed technical standards, and, increasingly, China is using its advances in science and technology as instruments of foreign policy. A notable example is seen in the promotion of Chinese technologies and cooperative research projects in President Xi Jinping's signature foreign policy program, the Belt and Road Initiative.

Today's discussion of decoupling comes on the heels of 40 years of increasingly intimate scientific and technological cooperation between the two countries. US and Chinese firms are linked by complex international supply chains, technology sharing, and research collaboration. Chinese authors are now the most numerous collaborators for Americans on scientific papers, and American authors are the most numerous collaborators for Chinese researchers. Between 2006 and

2016, some 50,439 Chinese scientists received PhDs from US universities, and about 70% of Chinese recipients of US advanced degrees in science, technology, engineering, and mathematics—the STEM fields—have made their careers at US institutions. Any efforts, then, to separate US and Chinese science and technology innovation systems are not simple mechanical acts, such as the decoupling of railroad cars. After four decades of scientific cooperation and educational exchanges, the relationship is better understood in organic terms, with nerves and blood vessels increasingly interconnected. Metaphorically, the separation should be understood less as a feat of mechanical engineering and more in terms of radical surgery. Likewise, we need to be prepared for infections and other serious postoperative complications.

Emerging peer

Whereas both nations have gained from the relationship, proponents of decoupling on the US side focus more on the benefits that have accrued to China, and on the fact that scientific cooperation, technology transfer, and especially the advanced training accorded to Chinese graduate students at US institutions have been critical to the impressive pace of China's scientific and technological progress. These ties are now seen by many in the United States as enabling the rise of a formidable competitor, if not a threat to national security, hence the Trump administration's current attenuation of scientific and technological ties.

Whether US policies will be effective in holding back China's technological progress, though, remains to be seen. For example, the extent to which Chinese flagship industrial enterprises such as the telecom equipment suppliers Huawei and ZTE have been shown to be dependent on US technologies—especially in semiconductors, new materials, key components for advanced manufacturing, and operating system software—indicates the degree to which China lags behind in key areas of high technology and points to the costs that can be imposed on China's technological development by the United States. In areas of scientific cooperation and graduate education, China surely will also have to absorb disruptions and setbacks, especially in the training of high-level talent.

On the other hand, as seen by Huawei's apparent success in producing a new 5G mobile network base station without US components, pressures from the United States could stimulate renewed efforts in China to build more independent systems for research and innovation. Proponents of this view would call attention to the mobilizing effectiveness of Chinese nationalism and to the story of the last time a scientifically and technologically superior partner discontinued relations for political purposes. In the 1960s, the break in relations between the Soviet Union and China reinforced the mobilization of technical talent and material resources to push forward China's strategic weapons programs. These "two bombs, one satellite" (*liangdan yixing*) programs have an iconic status in China and inspire belief in science policy circles today about what can be accomplished under hardship conditions.

The China of today is, of course, notably different from that of the 1960s, and the leaders of China's technical community recognize the limits of the *liangdan yixing* model in a marketized and globally connected China. Nevertheless, themes of nationalism and self-reliance now run deep in China and are being appealed to again in the face of US pressures. For Xi Jinping, "self determination in innovation is the unavoidable path ... to becoming the world's ... leading player in technology."

More than in the 1960s, however, today's nationalistic appeals are to an advanced and sophisticated research system capable of meaningful scientific and engineering achievements, albeit inspired by and borrowing from science and technology from the United States and other countries. With reference to common indicators of scientific and technological strengths—workforce, research and development expenditures, research infrastructure, output measures such as publications and patents, and impressive engineering achievements—China has clearly emerged as a leading player in science and technology. Chinese R&D expenditures are second only to those of the United States, and now constitute 22% of the global share. China competes with the United States in producing PhDs in STEM fields, and leads in the total number of publications in science and engineering. The quality of Chinese publications has also improved, with Chinese authors now contributing roughly 9% of the top 10% of highly cited papers (up from 5% in 2005). In 23 of 30 "hot" fields with clear technological applications, China published more high-impact papers than the United States between 2013 and 2018, according to a recent report from Nikkei and Elsevier. China has made notable achievements in space technology and in civil engineering for large infrastructure projects, including the construction of an impressive high-speed rail network, and is forging ahead in the construction of world-class "big science" research facilities, such as FAST (Five-hundred-meter Aperture Spherical Radio Telescope).

But do these impressive measures of achievement indicate a capability for sustained, independent development in the face of the kinds of pressures emanating from the United States—and in a context of growing uneasiness over China's scientific and technological cooperation with other scientifically and technologically advanced countries that are also troubled by its rise? An answer to this question calls for reflections on key features of scientific and technological progress in China, the limitations of such progress, and the broader sociocultural and historical contexts in which Chinese scientific development is unfolding.

Science and the Party

By prescribing the nature of economic institutions and relations between state and society, the Chinese political system strongly influences the nature of Chinese science and technology. Science is to be led by an amalgam of the Chinese Communist Party and the state, and is to serve national needs as defined by the state. Following the principal of "top-level design" (*dingceng sheji*), funding and other policy preferences flow to state-owned enterprises, universities, and research institutes in the hope of creating internationally competitive national champions in technology-based industries employing cutting-edge know-how. The sense of science as a self-governing professional community enjoying high levels of autonomy fits awkwardly with the dominant political formula. State-directed and -supported science incentivizes high-prestige scientists and technical entrepreneurs to cultivate relations with government officials in order to gain access to funds to support their own research networks and firms, thus helping to create conditions for waste, fraud, and other forms of misconduct. However, in spite of known problems with the system, for China's leaders, strong state leadership of science is taken as an article of faith.

The Party's current innovation-driven development strategy is a manifestation of its strong commitment to science and technology, but policies for scientific and technological development are now paired with the promotion of Xi Jinping's theory of governance, which calls for robust leadership by a disciplined and "professionalized" Party. In recent years the role of the Party in research, educational, and industrial organizations has therefore been strengthened. Although Party leadership supports prodevelopment policies such as generous infusions of funds, ongoing reforms to correct systemic weaknesses, careful analyses of international trends, and detailed science and technology plans incorporating benchmarks from those international comparisons, the leadership also introduces elements of political rigidity that seem to be antithetical to the genuine creativity that the state now seeks to foster. As *The Economist* recently noted, "the idea that you can get either truly reliable science or truly great science in a political system that depends on a culture of nonappealable authority is, as yet, unproven."

The complex interactions between China's exposure to international science and technology and its indigenous development experiences have created challenges in finding the right balance between policies for importing technologies and ones for promoting domestic research. A degree of cultural ambiguity underlies how the challenges are approached. The international environment—especially interactions with the United States—has strongly influenced the speed and direction of Chinese science and technology. At the same time, since China opened its doors to these interactions, it has put in place a series of domestic research, educational, and industrial policies to enhance indigenous capabilities and facilitate the assimilation of the flows of knowledge from abroad. Though this dual-track strategy has been largely successful, there are inherent tensions, reflecting the broader tensions of nativism and cosmopolitanism that characterize modern Chinese history.

Advanced study and research opportunities for Chinese students and scientists coming to the United States allowed China to effectively overcome the setbacks to science and education brought by the Cultural Revolution, leading to the production of a cadre of scientists and engineers familiar with research and technological innovations at the international frontier. And commercial relations between the two countries over four decades facilitated extensive technology transfer that has fueled the rapid rise of Chinese industry. Often overlooked in discussions of these relationships, though, are the transfers of policy models and managerial best practices—embodying Western values—that provide soft infrastructure for effective learning and knowledge transfer. Inspired by these international policy models, China developed extensive science and technology information capabilities and policy analytic centers that have become highly capable in monitoring international best practices against which Chinese performance is benchmarked. These experiences have stimulated powerful trends in China toward an internationalism grounded in global awareness.

And yet, much of this experience masks deep nationalistic sentiments and anxieties over dependency. China's need to learn from the United States and other technologically advanced societies is ultimately driven by an intense desire to overcome national weaknesses and feelings of inferiority resulting from the humiliations of modern Chinese history. Whereas policies pushing "indigenous innovation" and the mastery of "core technologies" aim at reducing technological dependency, they are also meant to demonstrate a new level of cultural capability, signaling China's arrival as a major science and technology power.

Chinese experience is thus characterized by ambivalence toward its reliance on foreign science and technology: an admiration of things foreign, leading to technological, cognitive, and psychological dependencies, coexists with the embrace of a scientific and technological nativism in support of self-reliance and indigenous capabilities. Though the pressures on China from current US policies can be expected to upset the beneficial relations in science, technology, and innovation China has enjoyed, they can also be expected to reinforce a deep-seated belief in China's ability to succeed on its own efforts.

Chinese fusion

Pressures from the United States could stimulate a more effective integration of the diverse parts of the Chinese innovation system than China had formerly been able to achieve. There has long been a divide in China between the research system (centered in universities and the Chinese Academy of Sciences) and the industrial enterprise. Until recently, the latter lacked a strong research orientation, and since the initiation of economic reforms and the introduction of market forces, Chinese industrial companies have typically sought proven technologies from foreign suppliers at the expense of longer-term developmental cooperation with an increasingly capable academic research system. Research institutions, in turn, have been producing internationally recognized publications and novel technologies, but lacked a strong commitment to the hard tasks of innovation in cooperation with domestic industry.

Over the past decade, reform policies have attempted to correct some of these research-to-production problems. The industrial sector has been designated as the main force of the national innovation system, and companies have been provided a variety of favorable policy incentives to promote research and innovation. The industrial sector now accounts for roughly 80% of the nation's R&D expenditures.

This number must be seen in context, however. Although China's leading high-technology firms have become major R&D performers, the R&D intensity of the great majority of Chinese enterprises is still exceedingly modest, hovering well below 5% of sales (compared with the 15%–20% typical of high-tech firms in the United States). And overall, the great bulk of Chinese R&D goes for the "D," with basic and applied research accounting for only about 15% of total national effort. As a result, except for the star players on China's high tech national team, Chinese firms lag in new product innovations and global brands.

Other policy initiatives of the past decade have incentivized universities and government research institutes, including the Chinese Academy of Sciences, to take the challenges of serving the economy far more seriously, with the result that some of the worst research-to-production problems are now being overcome. Life under conditions of today's technology war is likely to produce a closer coupling of the technical community with national defense objectives as well. Chinese efforts to promote closer relations between research organizations and military users through the promotion of "civilian-military fusion," for instance, are also enjoying high-level support, in part as a result of US policies. Pressures from the United States, in short, risk leading to a more effective integration of the diverse parts of the Chinese innovation system, to broad benefit in China, including its military operations.

Do China's impressive measures of achievement indicate a capability for sustained, independent development in the face of pressures emanating from the United States?

Pressures from the United States are also leading to a new focus in both countries on Chinese technical talent. Over the past 40 years, a much-improved higher education system in China has churned out large numbers of science and engineering graduates, making China's pool of science and engineering expertise the largest in the world. During the same period, however, many of China's best and brightest have sought graduate training abroad and built distinguished careers outside the country. China, of course, would like to encourage that talent to return, especially researchers in fields given high priority in national research policy. An especially interesting case has been China's domestic programs of advanced education in artificial intelligence, which have led to a significant growth in China's talent base in this area. Elite Chinese artificial intelligence personnel are now estimated to constitute about 18% of the global total. But as in other areas where top talent from China migrates elsewhere, roughly three-quarters of this elite cadre are working outside China, principally in the United States, where they are employed by Google, IBM, and top universities.

The Party-state has initiated various talent programs to provide incentives for attracting Chinese scientists and engineers back to China. These programs are now the focus of considerable attention in the United States since they are believed to have led to the transfer of cutting-edge science and technology to China and to violations of US research policies and protocols pertaining to conflicts of interest, research proposal reviews, and intellectual property protection. US concerns have been laid out most recently in a new US Senate report, *Threats to the US Research Enterprise: China's Talent Recruitment Plans.*

Though these programs have had considerable success in returning talent and technology to China, many leading scientists have nevertheless preferred to maintain their primary professional bases in the United States, attempting to balance their commitments to their professional careers against the residual feelings of Chinese patriotism. Whether US policies to curb the abuses of the talent programs will tip that balance and drive leading researchers back to China remains to be seen, as does the larger question of the future of the extensive trans-Pacific "brain circulation" of which Chinese professionals are major part. Well-publicized prosecutions and terminations of employment of Chinese scientists and engineers in the United States, prompted by purported national security concerns, have created an atmosphere of discomfort for many ethnic Chinese professionals at US institutions. The new atmosphere may make a return to China more attractive for some; for others, commitments to a life in the United States, and a more cautious approach to collaborations in China, may be strengthened.

Catch-up vs. leapfrog

Over the past 40 years, Chinese policy thinking has focused on catching up with more advanced countries in established industries, with simultaneous visions of leapfrogging to prominence in new fields. As China struggles now to compensate for the various losses coming from deteriorated relations with the United States, increasingly its focus will be on the leapfrogging agenda and the political economy gains that can flow from it.

Chinese science and technology policy thinking reflects an awareness of the problems emanating from the country's development experience—the strong reliance on foreign science, technology, and policy models—and the country is cognizant of the problems of being a latecomer to scientific and technological prominence. But even as Chinese policies have focused on catching up with the advanced countries, its leaders have recognized that, more often than not, China's fate is to be a follower in established industries and technologies. These policies have made China a successful "fast follower," one capable of important incremental innovations on the technologies of leaders, but a follower nonetheless. But the churn of Chinese policy thinking has always included thoughts of leapfrogging to radically new science-based industries in which China will secure a technological leadership position in terms of technical standards, patents, and ability to attract the best minds from other advanced nations.

China might therefore be prepared for setbacks from the technology war in some areas of high-technology industry where international dependencies persist, including commercial software, semiconductors and other established areas of electronics, and conventional automobile technologies, among others. But pressures from the United States can be expected to lead to renewed efforts to push research toward technological frontiers in new areas of high value-added production. Thus, in addition to a national strategy around artificial intelligence, China is making major commitments to such fields as new energy technologies, electric vehicles, the Internet of Things, quantum computing, and quantum communications, and is establishing an expanded agenda of basic research in such fields as neuroscience and new materials. In the area of defense technologies, leapfrogging aspirations focus on such technologies as hypersonic weapons, electromagnetic field guns, aircraft carrier-killer missiles, stealth drones, advanced combat weapons, and deep ocean capabilities. The success of the leapfrogging agenda, though, will depend on an enhanced capacity for fundamental research.

Toward two cultures?

China's strained relationship with the United States creates new planning uncertainties and makes the role of international cooperation in science and technology a central concern. The challenge of moving beyond catch-up requires a new strategic orientation for science, technology, and innovation policy and research programming, and work on the development of a new long-term plan—to replace the 15-year Medium to Long-Term Plan of 2006—has begun. But the very success of China's efforts to expand its capabilities in science, technology, and innovation, combined with residual problems with the innovation system, has also created a climate of introspection as to where the nation will go next. If China faces decoupling, what does that mean for the development of a Chinese scientific tradition and its cultural foundations?

This climate of introspection includes broad discussions of science and society and how the concept of scientific culture should be understood. To that end, the China Association of Science and Technology and Peking University recently established an Institute of Chinese Scientific Culture to explore how science should be understood in the contexts of Chinese history and cultural traditions. The roots of the current discourse on scientific culture can be found in the conflicts over cosmopolitanism, but the discussion is also being driven by two more immediate concerns.

The first is the belief that cultural factors may be inhibiting the development of a much-needed, strong basic research tradition in China. Although expenditures on basic research have increased notably in recent years, they are still dwarfed by spending on technological development, in keeping with the applications-oriented motifs of state policy and its emphasis on service to national needs.

The applications orientation has been furthered by the unleashing of market forces over the past two decades and the incentivizing of the research community to seek fame and fortune in the marketplace. For those in the Chinese technical community hoping for an improved environment for basic research, the resulting culture of "quick success and short-term gains" (*jigong jinli*) is characteristically antithetical to scientific culture as understood internationally. Though useful, perhaps, for an applications-oriented push to catch up in specific technological areas, the deepening commercial culture of science is, in the view of basic research advocates, inconsistent with the development of a research ecosystem of investigator-initiated projects, high degrees of investigator autonomy, long-term vision, and the high levels of tolerance for uncertainty and failure needed for building a successful basic research tradition.

Secondly, the scientific culture discussions are also driven by growing concerns over research ethics and the roles of the state, the marketplace, and professional communities in regulating the conduct of research in China. Problems of scientific misconduct are often linked to *jigong jinli*, as illustrated by the researcher He Jiankui's work on editing the human genome to produce genetically modified infants. Though widely condemned in China, He's work has led to reflections on the values and incentives in the research environment. For some observers, such as Liu Yadong, the chief editor of *Science and Technology Daily*, ethical lapses in research, scientific misconduct more generally, and the need for more focus on basic research are all matters of a flawed scientific culture, and a modern Chinese history that has failed to develop a "spirit of science" comparable to that which developed during the Enlightenment in the West.

A somewhat different take on the discussion around scientific culture is found in an editorial in China's *National Science Review* by its editor, the distinguished neuroscientist Mu-ming Poo. Poo attempts to understand the "spirit of science" less in Western Enlightenment terms and more in a Chinese cultural idiom. He acknowledges the importance for science of "universal values and norms that should not be biased by cultural differences." But he then goes on to suggest that "cultural and societal factors could influence how universal values and norms are perceived, accepted, and practiced." Poo notes, following the historian Joseph Needham, that "the dualistic view of science and technology inherent in the pro and con arguments for basic vs. applied research is quite alien to Chinese civilization," which embraces a more pragmatic, utilitarian approach. For Poo, this "utilitarian outlook of science is thus likely to influence future science development China." When seen in the context of the decoupling discourse, Poo's comments, and the broader discussion of scientific culture, point to a more self-consciously Chinese approach to the development of a scientific tradition, one that could also provide a normative framework for decoupling impulses. It is striking, after all, that the name of the new institute for studying scientific culture is the Institute of *Chinese* Scientific Culture.

As China faces an international environment influenced by US policies that are designed to weaken scientific and technological cooperation with China, and as it confronts a growing uneasiness with Chinese intentions and capabilities among industrialized countries more generally, China must assess its own developmental path, with its accumulated successes and failures. China is at an interesting point in its post-Mao history as it attempts to define a future direction for its science, technology, and innovation policies *and* the normative foundation of developing its scientific tradition. The significance of a prolonged technology war and a decoupling from the United States' innovation system is a critical question in its efforts to make sense of its current situation. US policies can impose costs on China in the short run, but the trajectory of Chinese development over the past several decades strongly suggests that China has the financial, human, and institutional resources to manage the costs over the longer run.

Decoupling impulses in both the United States and China already suggest that we may be witnessing a split in the ways that research and innovation are done in the twenty-first century—like driving on the right and driving on the left, as some in China now muse. Were the decoupling to continue, such a split would not only impose additional material costs on a globalized innovation system, but could also erode norms of universalism in science and opportunities for achieving international consensus on such critical questions as scientific integrity, ethical responses to new technologies, and the achievement of environmental sustainability.

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Recommended reading

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