MIT Technology Review

The China issue

120TH ANNIVERSARY ISSUE

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CHINA RULES

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It can be done

Gideon Lichfield is editor in chief of MIT Technology Review.

In November 2018 a Chinese researcher, He Jiankui, announced that he had produced the first ever gene-edited children. (MIT Technology Review was first to report that he had embarked on the attempt.) The story stunned and unnerved the world, not just because a medical taboo had been broken but because of where it had happened. It seemed to confirm China's popular image as a country with growing technological powers and few limits on using them.

Similar anxieties drove the US-China trade war that broke out in 2018 and the restrictions several countries imposed on Chinese telecom giants Huawei and ZTE. In November the US began to consider tighter controls on exports of AI and other technologies.

It's fortuitous but fitting, then, that this 120th anniversary issue of MIT Technology Review is about China's status as a rising technology superpower.

Two centuries ago China was the world's largest economy, with some 15 times the GDP of the US. But wars, rebellions, and a lack of industrialization made it stagnate. By the time our first issue appeared—sporting the walrus-whiskered president of MIT, James Mason Crafts, on the cover—the US was slightly ahead. By 1950 its GDP was several times larger than China's, which had scarcely budged in real terms in 130 years.

The Technology Review

ANNOUNCEMENT

Technology Review's first issue, in 1899, profiled MIT's president, James Mason Crafts.

Today, however, the two are once again roughly on a par, thanks to China's explosive growth since the 1970s. Visiting the country brings to mind the impressions of European travelers to America a century ago—of a land where everything is bigger and happens faster, a place bursting with energy and ideas.

Our goal in this issue was to answer the question "What is China good at?" The common prejudice that China doesn't innovate and steals all its intellectual property from abroad has been outdated for a while, but can its companies build world-changing products, and can its scientists win Nobels? Can it meet its goal, laid out in various long-term plans, of achieving supremacy in key areas of technology? Could its top-down system of government even make it better than the world's increasingly fractious democracies at tackling urgent problems like climate change? Or will the Xi administration's authoritarianism choke off innovation?

Our writers examine China's progress in autonomous and electric vehicles (page 24), microchips (page 28), nuclear power (page 42), high-voltage grids (page 48), space exploration (page 52), quantum computing and communications (page 56), and gene editing (page 62). We look at how the government has let the tech industry flourish while co-opting it into the growth of a surveillance state (page 8), wielded censorship and squeezed out foreign firms like Google (page 78), and bent scientists to its ideological will (page 70).

We profile Shenzhen, dubbed the "Silicon Valley of hardware" (page 16), explain how China is extending its geopolitical influence by building the world's biggest dredging industry (page 36), and analyze how the rivalry between China and the US may play out (pages 46 and 96). Finally, we sample the art that has sprung up critiquing the country's consumerist culture, internet aesthetics, and authoritarian tendencies (pages 14, 34, and 60), and end with a dystopian short story specially commissioned from one of China's leading science fiction writers (page 88).

I hope this issue leaves you with a picture of China's ambitions and its strengths, but also of its limitations. We believe both China and other countries have more to gain from collaborating than from driving up barriers to trade, travel, and the free flow of knowledge.

I'm interested in hearing your opinion, as well as what stories you think we missed. Write to me at gideon.lichfield@technologyreview.com and let me know.

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Land of giants

China's multibillion-dollar tech companies have thrived thanks to a government that provided incentives but stayed out of their way. Can they count on that in the future?

by Mara Hvistendahl

In the early 1980s, a cluster of fledgling computer companies opened up shop in a chaotic corner of northwest Beijing, near the campuses of Peking and Tsinghua Universities. Electronics Street, as the area became known, was a tangle of sturdy bicycles and hand-drawn signs, loud with heated bouts of haggling. Dusty banners hung over pedestrians' heads, while boxes of copy paper stacked 10 or 12 high blocked their path. Men in cheap suits hawked power strips and printer ink from street-side kiosks. Pirated software was so abundant that some preferred the moniker Crook Street.

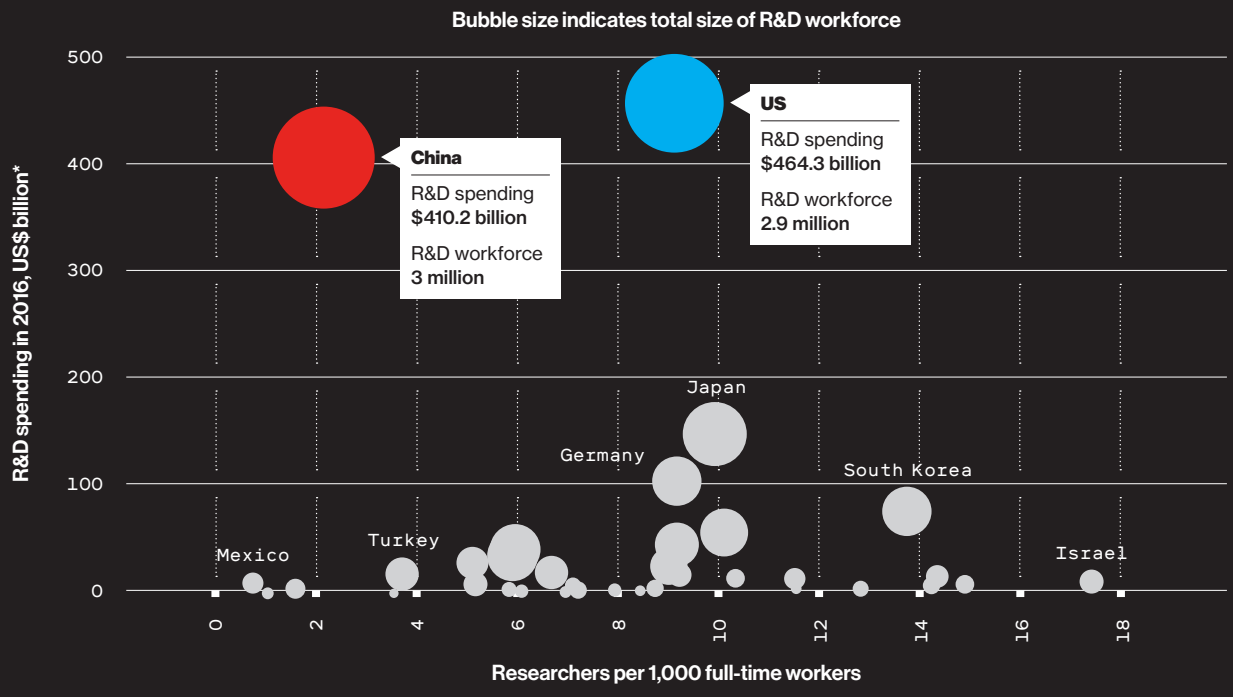
The existence of a burgeoning PC market was remarkable, given that many Chinese still did not own a refrigerator. But more remarkable was that the businesses of Electronics Street were private enterprises. Their foray into capitalism was an experiment launched with China's economic reforms, which early on were linked to investments in science and technology. Early signs suggested that this strategy might just work. Among the companies to emerge from the detritus of Electronics Street was Lenovo.

In the years since, China has undergone a scientific and technological renaissance. Between 1991 and 2016, government funding for research and development grew by a factor of 30. The country overtook Japan in spending on R&D back in 2009. The Organization for Economic Cooperation and Development predicts that it will outspend the United States by 2019. Today Electronics Street is known as Zhongguancun, and it is home to the tech giants Baidu, Didi Chuxing, and Meituan-Dianping, along with research centers for Microsoft, Google, and IBM.

China boasts nine of the world's 20 largest tech companies, including three in the top 10. The country can claim the world's largest single-dish radio telescope and several of the fastest supercomputers, and it plans

China's room to grow

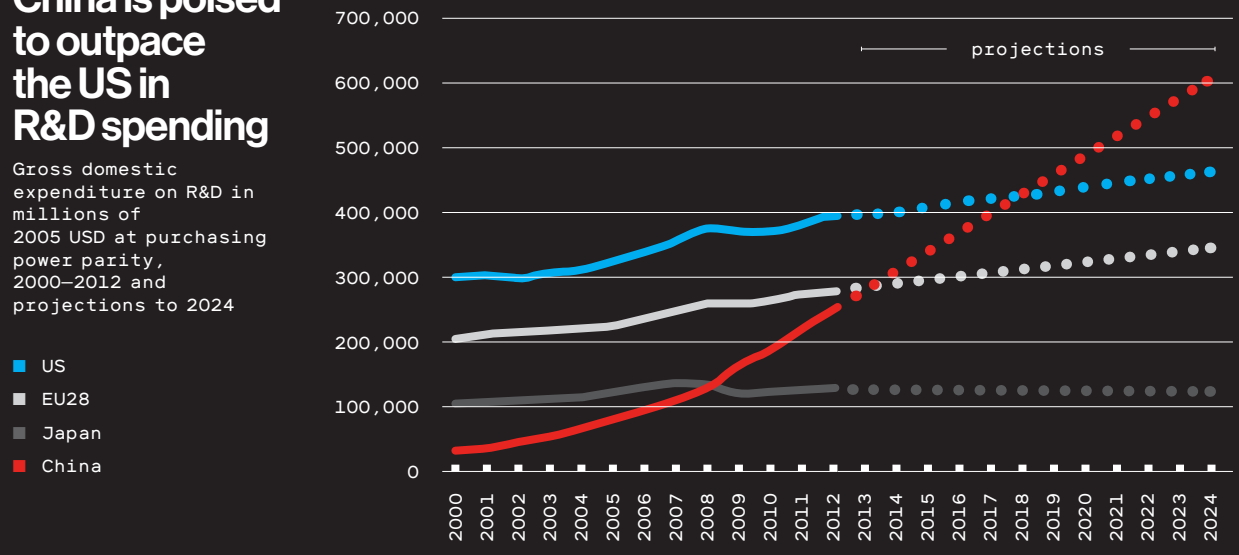
China's R&D workforce is similar to the US's in size, but small relative to China's population



*2010 dollars, at constant prices and PPP

China is poised to outpace the US in R&D spending

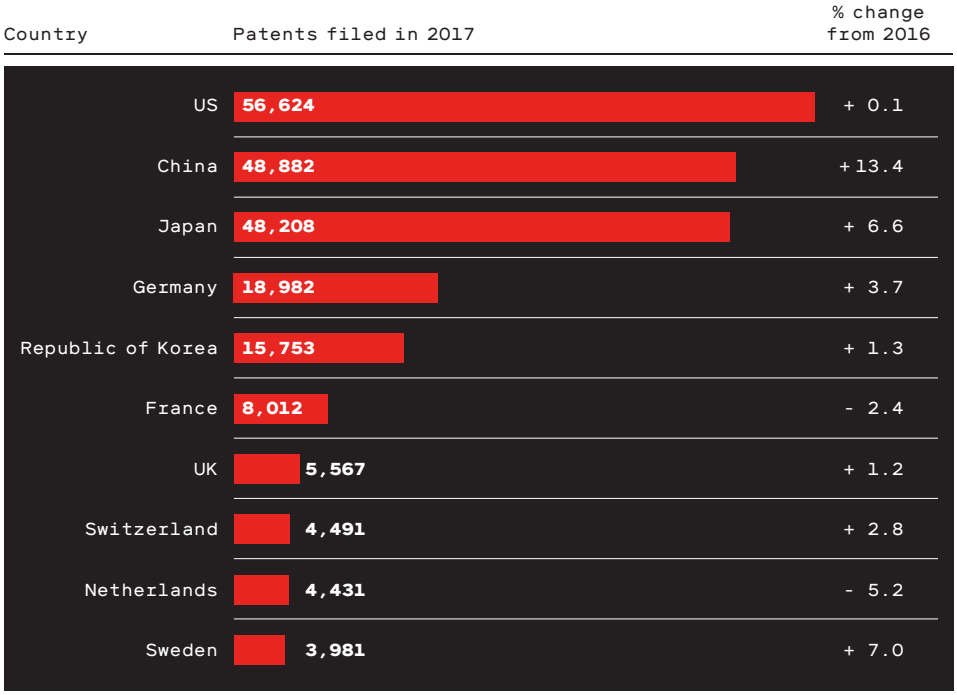
Gross domestic expenditure on R&D in millions of 2005 USD at purchasing power parity, 2000–2012 and projections to 2024



SOURCES: OECD, WORLD BANK

China is racing ahead on patents

Biggest filers of patents under international Patent Cooperation Treaty



to build the largest supercollider. In 2016, it launched the world's first quantum communications satellite. The ambitions charted in recent government plans are far-ranging: to excel in areas like 5G mobile technology, seed breeding, and robotics by 2020 and to become a world leader in artificial intelligence by 2030.

All of this has prompted considerable anxiety in the United States. Citing concerns about mercantilist market controls and industrial espionage, the Trump administration has plunged into a trade war with China. In October, Vice President Mike Pence accused the Chinese government of perpetrating "the wholesale theft of American technology."

To some extent, American talk about a technological cold war conceals a broad perception gap. While US lawmakers see in China's scientific aspirations an acute threat, Chinese commentators see a lingering insecurity. To them, the ambitions staked out on Electronics Street have not been fully realized. Government white papers and state press reports may project bravado, but in more intimate settings Chinese leaders lament that the country has spent much and gotten little to show for it. Yes, China funds big science projects, but that is not the same as achieving serious scientific breakthroughs or launching a product that reshapes the global market, like the iPhone. Even as China's elite universities climb the world rankings, the country can claim only one Nobel laureate in the sciences who did not do his prize-winning work abroad.

Yet there are signs that this may be changing. While a wave of homegrown Nobels may still be a way off, the country has seen an explosion of business innovation. The country's powerful tech companies, along with a few ambitious startups, are now shaping business models in Silicon Valley—and driving debate over internet controls and surveillance in the process. They have succeeded in large part because of a scrappy entrepreneurialism of the sort first seen on Electronics Street. As they get bigger and set their sights overseas, what holds them back may no longer be a lack of talent or resources. Rather, it may be their ties to the Chinese government—the very institution that set off China's tech boom when it began the economic reform program 40 years ago.

F

For years scholars asked: How can China innovate when science and technology are administered top-down? How can researchers achieve breakthroughs when there is no free speech, limited freedom of inquiry, not even access to Google Scholar?

Zhongguancun seemed like a telling example, at least at first. In 1989, some of the Electronics Street entrepreneurs joined the Tiananmen Square protests, which first took shape at nearby Peking University. When the crackdown came, Communist Party cadres were dispatched to Zhongguancun to coerce techies into denouncing the democracy movement. By the end of the 1990s, the area was formalized as a science park under more direct municipal government supervision.

Zhongguancun was deemed "China's Silicon Valley," a comparison that was absurd from the start. The top-down approach implemented in the years that followed is a far cry from the more decentralized innovation of the San Francisco Bay Area. It grew more absurd as the Zhongguancun model was replicated throughout China 167 times. By the early 2000s, many of these science parks struggled to attract high-caliber tenants. Some became mere distribution and processing centers for foreign technology firms.

The notion that simply populating China with science parks would lead to progress reflected a government emphasis on quantity and metrics at the expense of quality. Consider the Chinese technology plans. One key plan, adopted in 2006, mapped out growth targets to 2020. By that year, China aimed to spend 2.5% of

But many domestic Chinese patents are so-called junk patents that are not renewed after their fifth year.

SOURCE: WIPO STATISTICS DATABASE, MARCH, 2018

its GDP on R&D and excel in areas like biotechnology, nanotechnology, and drug development. Other goals included making China one of the top five countries in the world in both invention patents and total number of citations.

Some of these targets were reactive: the inclusion of nanotech followed the establishment in 2000 of the US National Nanotechnology Initiative, which provides more than a billion dollars a year in funding for nanoscience research. But they got a Chinese spin. After the 2006 plan was unveiled, local governments rushed to show their support by unveiling incentive schemes. Professors' salaries depended on how many papers they published in indexed journals. For companies, lucrative innovation subsidies hinged on getting large numbers of patents. Both the national and provincial governments devoted significant sums of cash to attracting back the tens of thousands of Chinese-born researchers living abroad, reasoning that they might jump-start innovation. Grant recipients were offered lucrative resettlement sums, along with salaries far above local norms.

The effect was dramatic, at least on paper. Output skyrocketed. Today China ranks first in the world, ahead of the United States, in the number of science and engineering papers published in international journals, according to the US National Science Foundation. The World Intellectual Property Organization places it second in international patent filings. In AI, one of the government's key strategic areas, China leads the world in both published papers and issued patents. It also leads in nanotech patents, according to an analysis by Tsinghua University's China Institute for Science and Technology Policy.

But look closer at these numbers and problems appear. Many domestic Chinese patents are so-called junk patents that are not renewed after their fifth year. The emphasis on publishing has led to a flourishing black market in academic publications. Shady agencies hawk ghostwriting services on the messaging app QQ, while enterprising researchers sell authorship spots on papers that have been accepted to indexed journals. Mainland authors are second only to those from US institutions in the number of English-language papers churned out every year, but many make little impact on global scholarship. Globally, the average English-language paper is cited 11.8 times; for scholars from Chinese institutions, the figure drops to 9.4 times.

A side effect of the enthusiasm for metrics is that less measurable areas, like teaching and mentoring, have suffered. Researchers are rewarded only for first and last authorship slots on papers, so many see little point in collaborating on large projects. Around the world, incentives often discourage work on big research questions requiring years to answer, but in China this is especially true. Bai Chunli, president of the Chinese Academy of Sciences, recently complained that China needs more scientists willing to "take a decade to sharpen a sword."

As spending on R&D has increased, a portion of the money has been spent on luxury cars, bribes, and mistresses. In one city in Guangdong province, science administrators reportedly pocketed 30% of the grant monies they handled. Money allocated for luring back scientists from overseas has been wasted as well. In Washington, Congress is worried about the Thousand Talents Plan, a recruitment program targeting foreign and overseas Chinese researchers. But Chinese leaders have a very different concern. Most of the Chinese scientists and entrepreneurs recruited under the program return to China only for part-time gigs and make little lasting contribution to research in the country. Some cynically see the grants as a sort of vacation plan—a way to fund visits to family and friends while keeping their tenured posts in the West.

One reason overseas Chinese scientists are reluctant to move back home is cronyism. With the Chinese Communist Party still firmly in control of most universities and research institutions, researchers are expected to spend time wooing administrators. Graduate students and postdoctoral scholars know that if they make a breakthrough discovery, their supervisor might swipe it.

And yet, despite all this, some areas of science and technology in China have flourished. Why? Critics like Pence are quick to point to China's absorption of foreign technological know-how through joint ventures, open-source collection, and blatant industrial espionage. Others cite its growing consumer population, which offers startups the prospect of instant scale. Certainly, both have played a role.

But there is another, less obvious reason for China's rise: the interaction of state directives with grassroots experimentation—or what a new book, *Innovation in China*, by Richard P. Appelbaum and several coauthors, calls the "often contradictory blend of heavy-handed state-driven development and untrammeled free enterprise." This is most evident with Chinese internet companies.

China has 9 of the world's 20 biggest tech companies

01	Apple	$838B
02	Microsoft	$833
03	Amazon	$816
04	Alphabet	$735
05	Alibaba	$407
06	Facebook	$396
07	Tencent	$389
08	Ant Financial	$150*
09	Netflix	$120
10	Uber	$120*
11	Salesforce	$107
12	PayPal	$99
13	Booking Holdings	$86
14	Bytedance	$75*
15	Baidu	$64
16	Didi Chuxing	$56*
17	Xiaomi	$41
18	Meituan Dianping	$38
19	JD.com	$31
20	Airbnb	$31*

MARKET CAP ON DEC. 4, 2018, OR MOST RECENT VALUATION - US$ BILLION

* = PRIVATE

SOURCE: KLEINER PERKINS

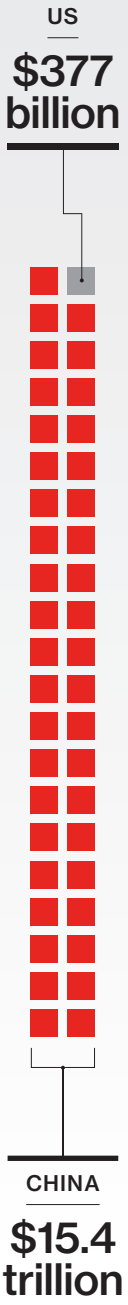
The leading tech companies Baidu, Alibaba, and Tencent are often referred to by the acronym BAT. That term hides a regional and entrepreneurial breadth. Tencent is headquartered in Shenzhen. Alibaba and its affiliate Ant Financial are in

Hangzhou. Only Baidu is based in Beijing's Zhongguancun. The major thing the three companies have in common is that they have benefited from varying levels of blocking, throttling, censorship, and other measures that have hobbled foreign competitors in a market hungry for internet products.

A number of early Chinese sites were overt clones of censored American ones. Technical problems reinforced their advantage. Web traffic at the time was filtered through the Great Firewall in only three locations: Beijing, Shanghai, and Guangzhou. When foreign sites weren't blocked, or when users had access to workarounds, they loaded at sloth-like speeds. In the time it took to load a YouTube video summarizing *War and Peace* over a VPN, it was almost possible to read the book.

But the copycat sites were not anointed winners, at least initially. They battled it out with a pool of ruthless competitors "like gladiators in the coliseum," in the words of Kai-Fu Lee, a venture capitalist and former head of Google China. Fresh-faced entrepreneurs had the stamina to tweak their products until the interface and features were what Chinese people wanted—which often differed significantly from Western norms. They intuited that certain holidays and other cultural phenomena could be spun into blockbuster promotions. Alibaba, for example, used a national fascination with numbers to transform November 11 into the online shopping blitz Singles' Day, which now dwarfs the US's Black Friday in sales. They were also willing to resort to underhanded tactics to win market share. In his book *AI Superpowers*, Lee tells how the CEO of Renren, a Facebook wannabe, bought a URL that could have been mistaken for that of competitor Kaixin001, copied the user interface, and signed up his rival's customers. Kaixin001 was run out of business.

China's mobile payments market is 41 times the size of the US's



Most important, China's internet startups were willing to try out ideas that hadn't been proved elsewhere. One such idea was the integrated QR scanner—the technical tool that enables mobile payments within the apps WeChat and Alipay. QR codes link online and offline worlds in unexpected ways, turning basic objects like menus or bus schedules into a virtual experience and making it possible to move through a city with the constant aid of technology. Alipay introduced QR codes in 2011, a full year before US technologists unsuccessfully hyped them at the Texas tech festival SxSW. WeChat soon followed suit.

The scanners are a big reason that China's mobile payments market is now valued at $ 15.4 trillion, making it more than 40 times as large as the US one. That market underlies one of the fastest-growing sectors of the Chinese tech world: online-to-offline services. Startups enable consumers to order house calls from tutors, hair stylists, and dog groomers at a moment's notice. Companies like Ofo and Mobike have flooded cities in China with millions of dockless bikes, transforming public transportation. These new services are not without kinks—Chinese cities have struggled to deal with massive bike-share graveyards—but they have made the lives of many middle-class Chinese infinitely more convenient. Megacities no longer feel so daunting when you know that you can farm out unpleasant daily tasks, or hop on a bike if you can't find a taxi.

Chinese tech companies have done so well at this sort of experimentation that the direction of copying has reversed, with US tech companies now borrowing ideas from the mainland. The CEO of Kik, Ted Livingston, has said he aims to make the app the "WeChat of the West." (He got $50 million in financing from Tencent.) Ofo and Mobike have expanded throughout the world, inspiring copycats everywhere—though they have foundered in less densely populated cities where mobile payments aren't so popular.

It is this frenetic energy and intense competition, not Chinese government attempts to pick winners and set targets, that is driving innovation in China. Across sectors, the most exciting companies began as renegade startups. Genetic-research powerhouse BGI spun off from the Chinese Academy of Sciences in Beijing, but later moved to freewheeling Shenzhen. Drone maker DJI was founded by a university student working out of his dorm room in Hong Kong. The speech-recognition firm iFlytek was started by a group of PhD students in Anhui province. Small and medium-sized enterprises produce 80% of China's most innovative products, according to a World Economic Forum white paper.

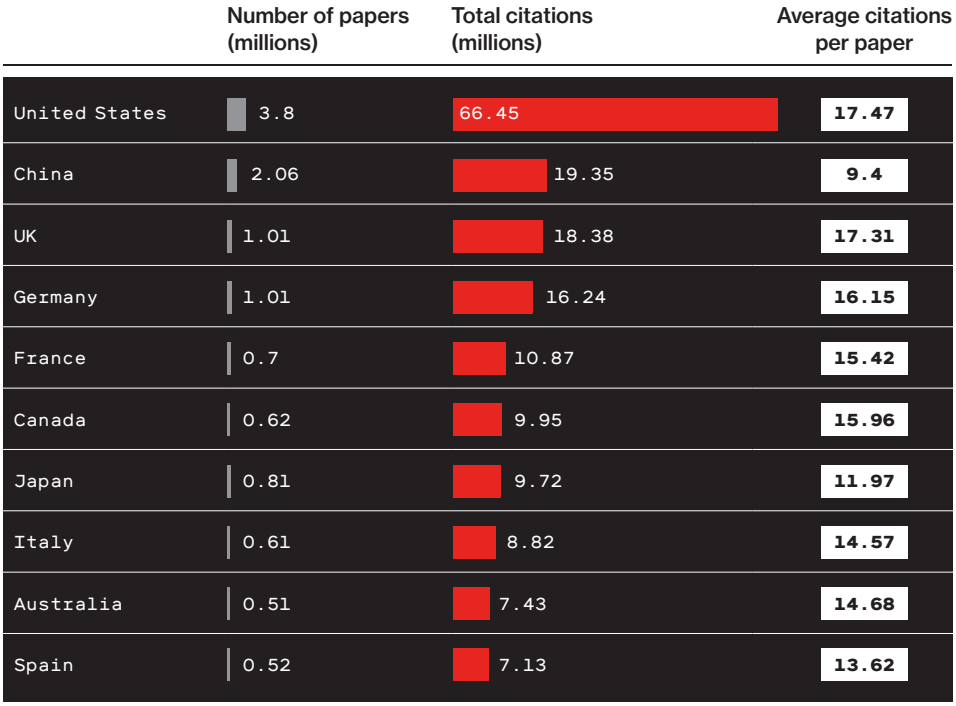
The first wave of Chinese innovation is in business models, not the technological breakthroughs targeted in government white papers. But one may drive the other. As they mature, China's tech giants are opening research facilities overseas and focusing on areas like AI and self-driving cars. Baidu, which aims to have half the users of its maps app come from outside China by 2020, has two research facilities in the Silicon Valley suburb of Sunnyvale and a third in Seattle. iFlytek will open its own center in the Bay Area later this year. As these companies hire researchers from a broader variety of backgrounds and absorb ideas from abroad, they may finally have a chance at producing a world-changing product like the iPhone.

But that's if their ties to the Chinese government, in its growing crackdown on political opposition, don't interfere.

SOURCE: SOUTH CHINA MORNING POST

Chinese scientists publish but underperform

Global publication and citation activity tracked by the Web of Science database between 2007 and 2017



SOURCE: INSTITUTE OF SCIENTIFIC AND TECHNICAL INFORMATION OF CHINA

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Several times a year, the 25-person Politburo gathers for a "study session" on a topic of pressing concern to the Party, like market reforms or civil unrest. Typically, these are held at the Party's Zhongnanhai complex in central Beijing. But on September 30, 2013, officials wearing matching windbreakers, dark trousers, and sensible leather shoes boarded a bus with tinted windows and rode to Zhongguancun for the first session ever held off site. There, Xi Jinping gave a speech about technological ascendance. "We must seize the opportunities presented by this new phase of technological revolution and industrial change," he avowed. "We cannot wait, we cannot watch from the sidelines, we cannot slack off."

The next year, the government unveiled a push for "mass innovation." Premier Li Keqiang announced that startups would be nurtured and incubators established throughout China. For years, grassroots experimentation survived without much state encouragement, and in some cases despite strong-armed intervention. Now, finally, it is being supported.

Zhongguancun has gotten a $1.5 billion face-lift. The vestiges of Electronics Street have been cleared out to make way for shared workspaces, incubators, and startup offices on a pedestrian street called Inno Way.

This shift in policy is an encouraging development. But if China's tech startups are now nurtured, they are also increasingly co-opted. Unlike the internet or free scholarly inquiry, mobile payments and facial recognition do not threaten authoritarian rule; they reinforce it. WeChat payment data can reveal where a person went on a particular day, down to the minute. An advanced facial-recognition system can tell where that person is right now. Since he took office in 2012, Xi Jinping has moved to swiftly consolidate power, stifle dissent, and persecute China's Uighur Muslim minority. The tech companies have been enlisted in that quest.

According to Human Rights Watch, iFlytek is helping the Chinese government develop a national biometric database for voice recognition, with the goal of identifying speakers in phone conversations. (iFlytek has a research collaboration agreement with MIT's Computer Science and Artificial Intelligence Laboratory.) The company Leon Technology manages surveillance infrastructure in Xinjiang, where as many as 10% of adult Uighurs are forcibly held in internment camps. SenseTime, one of the world's leading makers of face-recognition software, has set up a joint venture with Leon Technology. Tencent and Ant Financial are piloting electronic national IDs that are embedded inside WeChat and Alipay. Ant Financial enforces government blacklists by penalizing the blacklisted in its Zhima Credit program. In 2017 BGI launched a genetic testing center in Xinjiang, where authorities are collecting DNA from Uighurs.

Globally, the average English-language paper is cited 11.8 times.

For scholars from Chinese institutions, the figure drops to 9.4 times.

Such alliances could foil the companies' efforts to create breakthrough products that appeal to consumers around the world. Worries about surveillance have already blocked Huawei's phones from the US, though it still ships more of them worldwide than Apple. If Chinese tech companies face more concerns from overseas, they might try to distance themselves from the more nefarious government projects.

The effort to please government interests could also stifle innovation in a more fundamental way. As product life cycles accelerate, companies need to be agile to keep up. It is hard for them to do so when they have to gauge policy direction in a state that is still fundamentally opaque.

Still, it would be a mistake to underestimate the Chinese tech firms' resourcefulness. Bets against the emergence of innovation in China have so far been losing ones. That may remain true even as the state tightens its grip.

Mara Hvistendahl is a US-based science journalist who spent eight years in Shanghai.

THE ART OF TECH

1 OF 3

Consumerism

The rise of a distinctive e-commerce culture is among the most striking changes the internet has wrought in China. Over $30 billion in merchandise traded hands on Alibaba platforms alone last November 11, a consumer holiday known as Singles' Day, which dwarfs the US's Black Friday. Most of those sales took place on Taobao, Alibaba's principal consumer-facing website and app. *Running on Taobao*, a series by Hong Kong artist **Mak Ying Tung 2**, comprises photographs of oversized treadmills that Mak found on Taobao. She enlarged the stock photographs and embedded stills from movies like *Iron Man* and *Star Wars* on the treadmills' screens to present an absurd and unsettling vision of humanity enslaved to in-app purchases and streaming entertainment. If Taobao has given rise to a new consumerist creed, artists like Mak are articulating a speculative iconography to match. —*Josh Feola*

publication:
Open Sesame

project:
The Real Thing issue

One can glimpse the diverse needs that Taobao's 620 million users sate online by flipping through the inaugural issue of the Beijing magazine Open Sesame, which made a compendium of oddball items sold on Taobao. The goods range from the merely bizarre (a portable, one-person sauna) to the perversely intimate (miniature sex dolls).

COURTESY OF OPEN SESAME; COURTESY OF DE SARTHE GALLERY

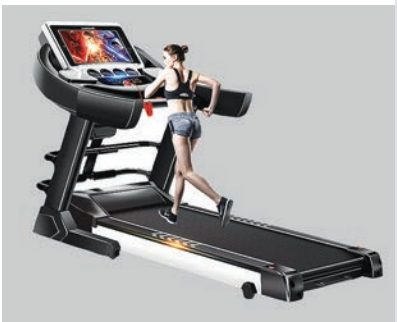
artist: Mak Ying Tung 2 _____ project: *Relics*

In Mak's *Relics* series, turn-of-the-millennium consumer electronic devices such as the CD Walkman and original Nintendo Game Boy are rendered in the grandiose style of religious icons. In Mak's view, these once-cherished objects have been transformed into quaint artifacts of a pre-smartphone past—relegated to history's trash heap.

artist: Mak Ying Tung 2

project: *Running on Taobao*

Mak uses Marxist theory to analyze the depersonalized, ubiquitous nature of relationships between buyers and sellers on Taobao, which has its own slang lexicon. She says, "Class and the relations of production are hidden behind the rhetoric of the internet."



Shenzhen is still a place where sweatshops churn out cheap knock-offs. But it's evolving.

The city has given the world viral "hardware memes"—products like the electric balance board.

A scooter on every corner

Shenzhen flooded the world with cheap gadgets. Can it now become what Silicon Valley never did—a global hub of innovation, entrepreneurship, *and* manufacturing?

By An Xiao Mina and Jan Chipchase

Like websites' tests of headlines to see which get the most clicks, the process known as shanzhai gives rise to countless variants of a product.

Rex Chen (see page 22) shows off the electric skateboard that he crowdfunded on Kickstarter.

JONATHAN LEIJONHUFVUD (DRONES); COURTESY OF THE AUTHORS

At around 5 pm, the streets of Huaqiangbei are filled with people transporting the day's orders to be shipped.

In Huaqiangbei's maze of stores, every gadget imaginable is for sale.

Fidget spinners are another of the shanzhai-fueled global crazes.

A drone in every sky

Street-side drone sellers demonstrate their products outside building 3 of the Huaqiang HQ Mart complex.

Products are shipped out from Shenzhen to just about everywhere in the world.

Every day at around 4 p.m., the *creeeek criikkk* of stretched packing tape echoes through Huaqiangbei, Shenzhen's sprawling neighborhood of hardware stores. Shopkeepers package up the day's sales—selfie sticks, fidget spinners, electric scooters, drones—and by 5, crowds of people are on the move at the rapid pace locals call *Shenzhen sudu*, or "Shenzhen speed," carting boxes out on motorcycles, trucks, and—if it's a light order—zippy balance boards. From Huaqiangbei the boxes are brought to the depots of global logistics companies and loaded onto airplanes and cargo ships. In the latter case they join 24 million metric tons of container cargo going out every month from Shekou harbor—literally "snake's mouth," the world's third-busiest shipping port after Shanghai and Singapore.

A few days or weeks later, the boxes arrive in destinations as nearby as Manila and Phnom Penh and as far afield as Dubai, Buenos Aires, Lagos, and Berlin. They appear in the world's largest cities and smallest villages: selfie sticks held up in front of Indian temples, a (rebranded) Xiaomi electric scooter cruising down San Francisco's Market Street, and a DJI drone flying over pretty much anywhere. If your gadget says "Made in China," the chances are it came from Shenzhen.

From a population of 30,000 in the early 1970s, the city has grown to over 10 million, with gleaming high-rises, a modern transport system, and world-class retail. The local government gives grants for filing patents and for starting maker spaces. Gentrification and rising rents have made it the most expensive city in China, as the factories that fueled its boom move steadily outward into the rest of the Pearl River Delta.

Shenzhen is changing in other ways, too. Instead of just hardware (like hoverboards), it's making sophisticated products that combine hardware with software (just-in-time bookable electric scooters, app-controlled drones) and, increasingly, artificial intelligence (translation devices, toy robots, semi-autonomous vehicles). Moving beyond its reputation for developing cheap rip-offs of other people's ideas, it's become more of a hub that connects innovation, manufacturing, and knowledge all over the world.

This means Shenzhen could become something that Silicon Valley—for all its extraordinary concentration of money and talent—has never quite been: a technology hub with products available for every country and almost any budget. The question is whether it can keep adapting and growing in the face of three combined threats: burgeoning barriers to globalization, an increasingly authoritarian Chinese government, and the costs of its own success.

Shanzhai and the mountain bandits of tech

Most global consumers' first contact with Shenzhen came through products like the selfie stick. Seemingly frivolous, relatively easy to

JONATHAN LEIJONHUFVUD (MARKET); COURTESY OF THE AUTHORS

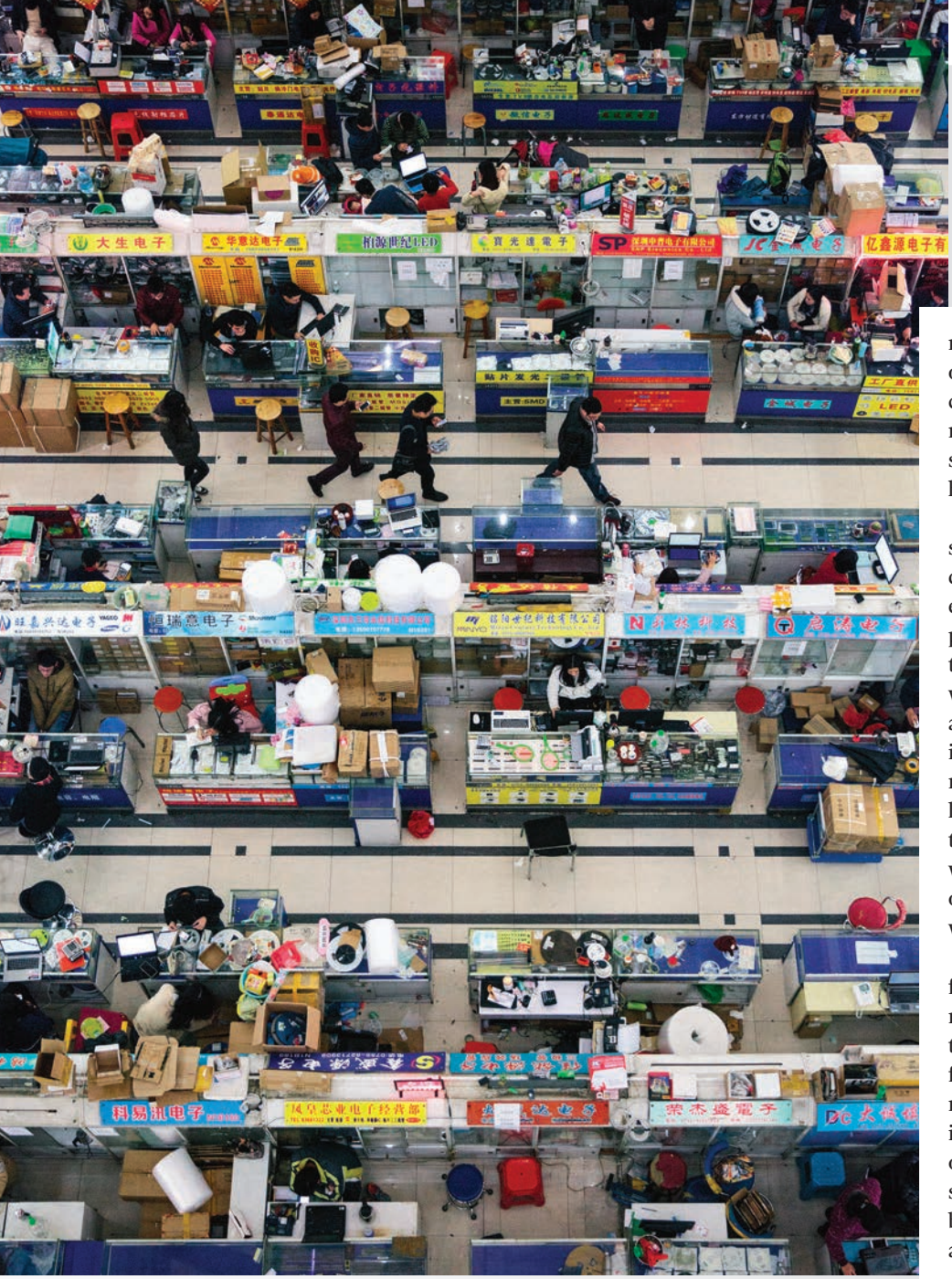
The three (and a half) eras of Shenzhen

Shanzhai era

A period characterized by the rapid manufacture of electronics, often copies of popular Western-made products, saw growth driven by global demand for entry-level smartphones, especially in emerging markets. Short product development cycles and an ecosystem of component suppliers delivered cheap but low-quality gadgets.

Formalization era

Three factors drove this period: Workers became more skilled and demanded higher wages. Successful companies had reputations to protect and moved toward branded products. And the government began to crack down on intellectual-property theft as it took steps toward its WTO commitments.



Shanzhai manufacturers can decide what to produce by visiting Huaqiangbei's vast market, where hundreds of factories maintain tiny storefronts.

2020

Maker movement

Following a visit to Shenzhen by Premier Li Keqiang in 2015, over a thousand "maker spaces" were set up to encourage companies to develop new products instead of copying existing ones. In reality, many were no more than coworking spaces, and almost all shut down after their business models failed.

Globalization era

A more mature innovation ecosystem has emerged that understands how to serve the global market. It's enabled by access to venture capital, global crowdsourcing platforms, primed sales channels, and the rise of a Chinese creative class that can work with global design norms.

manufacture, they were born of a process of product development and distribution called *shanzhai* (山寨). The term literally means "mountain hideout" (an apocryphal story traces its origins to factories in the hills of northern Hong Kong).

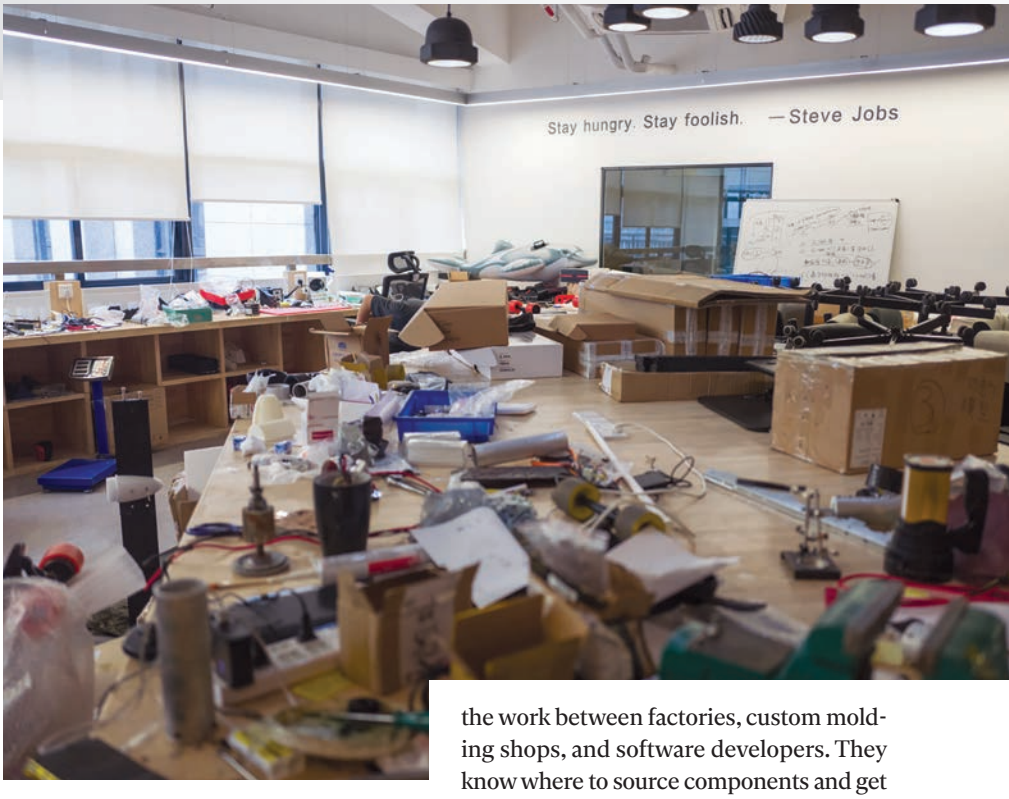
In much the same way that open-source software enables a global community of developers to copy and remix each other's work, rapidly creating variants on a piece of software to meet different needs, the *shanzhai* method delivered "hardware memes"—gadgets quickly designed and built out of easily sourced and readily interchangeable parts. Just as digital news outlets might test multiple headlines and tweets to see which one gets the most clicks, a *shanzhai* manufacturer would release 10 products with a mixture of copied and original designs, and go with whatever worked.

A product that took 12 to 18 months for a Western company to bring to market might take only four to six weeks within the *shanzhai* ecosystem. It was common for Western companies that announced a new gadget to find *shanzhai* versions of it on the shelves before they could put it on sale themselves. Many early *shanzhai* successes were copies of popular phones by brands including Nokia, Samsung, and Apple.

It's easy to dismiss these products as cheap knockoffs, but there was a lot of experimentation with new features, too. A notable example is the dual SIM card, a feature only recently introduced to Apple phones but available for over a decade in *shanzhai* products.

What made this experimentation possible was the Pearl River Delta's vibrant network of suppliers and small factories, and China's lax attitude toward intellectual property. Entrepreneurs could decide what to produce by visiting the sprawling Huaqiangbei market, where hundreds of factories maintain storefronts, often little more than two meters wide, to showcase their wares. A successful product in Huaqiangbei was easy for competitors to identify and copy, and Chinese brands were as susceptible to imitation as Western

Apple founder Steve Jobs inspires Shenzhen entrepreneurs in their search for the next global craze.



ones. A single hit, selling as few as 10,000 units, was sufficient to turn a profit and fund nine other market failures.

But while there will always be a market for the next fidget spinner, *shanzhai* has its limits. Companies whose products gain a foothold in overseas markets are also being exposed to those countries' intellectual-property laws. And as they graduate from fidget spinners and hoverboards to internet-connected lightbulbs and AI devices, they need more design and branding expertise.

If *shanzhai* had failed to evolve, it would have remained an interesting footnote in the history of globalization. But nothing in Shenzhen stays still for long.

From the factory floor to the design studio

A short taxi ride away from the bustle of Huaqiangbei are the offices of a design consultancy called Innozen. The calm open-plan space leads to a minimalist white meeting room with a shelf of awards, including several international design prizes.

Shenzhen suppliers provide components for just about anything you could want to produce.

"*Shanzhai* is a form of 'blindfold design,'" explains Innozen cofounder Michael Zheng. The process, he says, contains no overarching strategy, and "the technological barriers are constantly lowering."

Zheng's company is one of a new breed of consultancy, known locally as an industrial design company, that has sprung up in Shenzhen to help both Western and Chinese firms develop products (translation earbuds, smart pens, VR goggles) more sophisticated than what emerges from *shanzhai*. Zheng works closely with people like Donny Zhang, head of another kind of consultancy, an independent design house, which is like an engineering firm with some design skills.

Zheng and Zhang represent the new creative class in China. Educated in London and New York, respectively, they speak fluent English and Chinese and are as comfortable with Western design norms and aesthetics as with Chinese business culture and production processes. Together, they help clients realize an idea, orchestrating the work between factories, custom molding shops, and software developers. They know where to source components and get them assembled, but they also understand the needs and values of a global clientele.

Industrial design companies and independent design houses are the newest parts of a larger ecosystem of business services that includes incubators, coworking spaces, and fab labs such as the Shenzhen Open Innovation Lab (SZOIL), near the border with Hong Kong. SZOIL takes in foreign and Chinese makers alike, teaches them basic fabrication and prototyping skills, and connects them with design firms like Innozen.

Financing, too, has evolved. Budding *shanzhai* entrepreneurs had to borrow from component suppliers and family members. Now both venture capital firms and big technology companies like Xiaomi and

A bike-sharing boom has led to piles of unused bikes around the city.

The Shenzhen Open Innovation Lab teaches fabrication and prototyping.

Tencent invest in smaller teams' efforts. Sites like Kickstarter and Amazon also allow manufacturers to skip the rougher environs of Huaqiangbei and reach foreign markets directly. Online payment platforms like WeChat Pay and Alipay help streamline sales and costs.

As products get more advanced, they also become tied into a global software ecosystem and its norms. Many of the devices now available in Huaqiangbei use apps available on the Apple and Google app stores as well as the 360 Store, one of the main Android app stores used in China. They range from a "smart speaker" that taps into Amazon Alexa's API to app-controlled toys that sing and dance on cue and learn voice commands from users. The software is written by a community of developers emerging in a software park in Shenzhen's western end, as well as in the software hubs of Shanghai and Beijing. Such products require considerably more investment in design, software development, and user experience: during one studio visit, for instance, we passed a room full of workers training AI systems for autonomous vehicles.

This network of design, manufacturing services, financing, and software development, together with a growing recognition of the quality of Chinese products, is enabling Shenzhen companies to reach further into global markets. One example is the electric scooters that have appeared in cities around the world. The scooters themselves are all made in China, but the companies that brand and distribute them might be in Barcelona (Joyor), Mexico City (Grin), or California (Bird and Lime). In some cases competing distributors even use the same physical scooters, just with different branding and apps.

SZOIL founder David Li calls this the expression of "China as a service." Instead of having to learn to build electric scooters, Joyor, Grin, Bird, and Lime can focus on the work that requires local knowledge, like distribution and getting permits from city governments.

The Pearl River Delta of hardware

It's become fashionable to call Shenzhen the "Silicon Valley of hardware." Even though Silicon Valley's own name is derived from its role as the early epicenter of computer hardware, it's useful to examine the analogy.

Like Silicon Valley, the Pearl River Delta region contains a mix of expertise and capabilities. Its factories, component suppliers, service providers, and skilled workforce are difficult to replicate. Just as Silicon Valley benefited from the open-source software movement, Shenzhen grew thanks to the open-source-like production ecosystem of *shanzhai*. And the Delta resembles Silicon Valley in being not a singular geography but a globally interconnected one, attracting foreign investment and collaboration and exporting its influence on the world's technology infrastructure.

Shenzhen's rapid growth, though, has also come with human costs, many similar to those experienced in the San Francisco Bay Area.

The rising cost of living means many people from earlier waves of migration to Shenzhen can no longer afford to live there. Air quality has worsened, so factories and other polluting industries are being moved out of the city—along with the jobs that employed those first migrants. The pressures of urban life are compounded by the one-child policy China had until 2016, which puts a heavy burden on people looking after aging parents and grandparents. In a highly materialistic culture, standing still means falling behind: there is social pressure to get married, but that also comes with the expectation of buying an apartment and car. Women struggle to get promoted in a male-dominated working environment. Burnout is rife, and opportunities for exploitation are high.

Some of the constraints the city experiences, on the other hand, are unique to

A new generation of innovators work seamlessly in English and Chinese.

COURTESY OF THE AUTHORS

China. Even as more of the new products coming out of Shenzhen are internet-connected, the government of Xi Jinping is instituting tighter controls on the internet. While sites like Kickstarter and Amazon are not blocked per se, key ways of reaching international audiences, like Instagram and Twitter, are accessible only from the mainland through virtual private networks, which the government is making increasingly hard to use. WeChat Pay and Alipay, meanwhile, require a Chinese bank account, making it hard to take payment from foreign clients. All this hampers Shenzhen-based businesses' dreams of going global.

Finally, as powerful as the Shenzhen tech ecosystem is, it relies heavily on the existence of free trade and gray-market labor, both of which are under pressure—the former from a trade war between the US and China, the latter from growing demands for better wages by the Chinese middle class. Distrust of Chinese-made products abroad is growing: many internet-of-things devices, like smart plugs and security cameras, have been found to be easily hackable, and in early 2018 the heads of the main US intelligence agencies said Americans shouldn't buy phones from Huawei and ZTE because the Chinese government might be using them to spy on or interfere with American communications networks. This isn't just a China-US problem, but a global one of rising "technonationalism" that could dampen the rise of globalization.

But as the city's entrepreneurs have bumped up against these limits, they have started to transcend them by exporting not only Shenzhen-made products but the Shenzhen model itself.

Shenzhen everywhere

Take a few. They're very tasty." In his high-rise office in western Shenzhen, Robin Wu hands us a few grains of *moringa*, a slightly bitter seed eaten in Ethiopia for its reputed health benefits. He serves us Chinese tea in styrofoam cups, and as we talk, he glances occasionally at his phone for messages and at a three-screen panorama setup he has for video calls and demos. Wu, who made headlines in 2010 as the "*shanzhai* king" after he produced an iPad-like device within 60 days of Apple's releasing the original iPad, now owns and operates a series of factories in Ethiopia. Having started his Shenzhen journey by selling bootleg DVDs in the early days of Huaqiangbei, Wu is now part of a trend toward Chinese companies investing globally in manufacturing.

Shenzhen's rising labor costs, combined with the tit-for-tat trade tariffs that China and the US have imposed on one another, are encouraging factories to move not only outside the city but outside the country. This adds to an existing trend of Chinese investment in production around the world, especially in sub-Saharan Africa and Southeast Asia, spurred by the Belt and Road Initiative—the Xi administration's own program for expanding ports, railways, and other infrastructure across Asia, Africa, and Europe.

Exporting Shenzhen-style production sometimes also means exporting Shenzhen-style labor exploitation. A number of Chinese companies have been embroiled in scandals over pay and working conditions in Africa, for instance. It's also unclear whether the economic gains benefit both regions equally or are mostly flowing back to China. As researchers Deborah Bräutigam and Tang Xiaoyang have observed, Chinese economic cooperation zones conducive to trade have sprung up around Africa, but data on their impact remain slim.

Yet technologists in Africa and around the world are keen to learn from the Shenzhen model. "There's a real eagerness in Shenzhen in terms of reaching out and welcoming collaborations," says Seyram Avle, an assistant professor at the University of Massachusetts, Amherst, who has been studying connections between Shenzhen and the African continent since 2015. She's documented how entrepreneurs from countries like Ghana and Ethiopia might travel to China or use online services to build businesses for local needs, ranging from making phone chargers with LED lights to testing prototypes for agricultural and medical hardware. "I think the real hero of the story is the small-scale businesses in Accra, in Lagos, in Nairobi, in Shenzhen, reaching

JONATHAN LEIJONHUFVUD (MARKET); COURTESY OF THE AUTHORS

The Shenzhen product timeline

Rex Chen, a tattooed designer and engineer who moved to Shenzhen a couple of years ago, personifies the modern Chinese entrepreneur who understands Western sensibilities. He had an idea for an electric skateboard that could operate smoothly without an unsightly battery, and raised nearly $750,000 from over 1,100 backers on Kickstarter. He expertly navigates the complex web of services and manufacturing in Shenzhen, but he can test his products on the party scene in Shanghai and understands the ins and outs of the technologies he is crafting.

Chen reports that he has about three months from initial concept to launching and harvesting profits before copycats saturate the market. Component suppliers typically offer

Idea for new product

Engineering, design, testing

Month 1

Month 2

Take out loan for scale manufacturing, on 90-day repayment terms

An empty mall building near Anfang electronics market in Shenzhen bustles with people picking up and delivering packages.

Launch

Harvest profits before other manufacturers saturate the market

Month 3

Repay loan; profits fund next production cycle

90-day repayment terms. This allows Chen to fund the manufacturing run and reinvest the profit into his next concept.

"Chinese businessmen don't care about competition in the way that you do," Chen says. "The more people that are making the same product, the safer it is." Indeed, if an idea is new and unproven, component suppliers will require payment up front. This tends to lead to design evolution rather than revolution—for example, going from an electric skateboard to an electric scooter.

But the pressure to work faster is always there, Chen says. "We can go from concept to market in three months. But that is still one month too slow."

out across to each other and building things they think have value for their own people," Avle says.

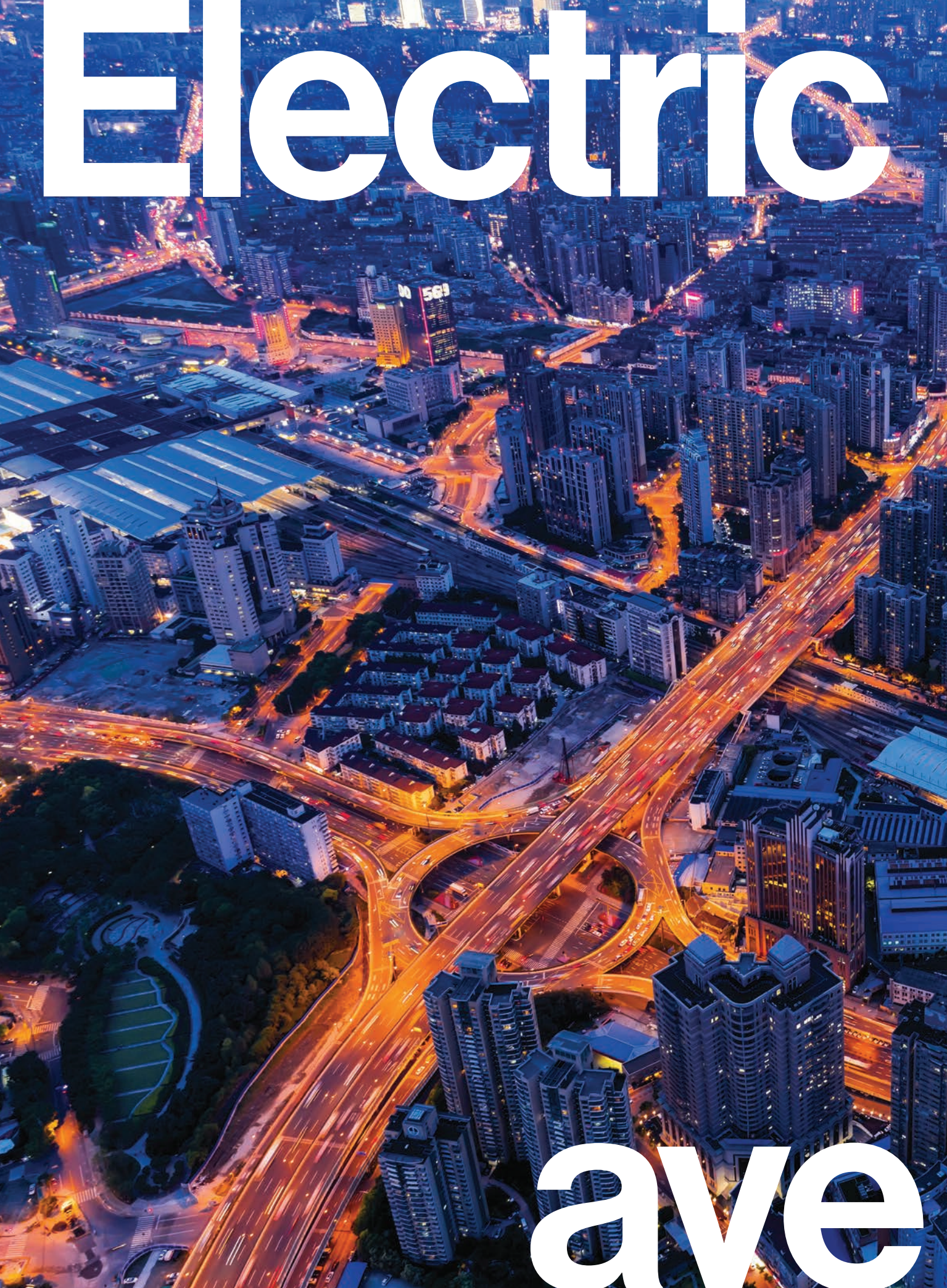
Shenzhen has also had a more indirect influence on the kinds of technology products the whole world is making. While hardware memes like selfie sticks and hoverboards fade from view after a flurry of attention, they—just like internet memes—leave behind echoes that crop up in new settings. The descendant of the selfie stick is the handheld gimbal stabilizer that, for as little as a hundred dollars, turns any camera into a semi-professional video platform. The hoverboard may have been a one-hit wonder fueled by social media, but scooters and balance boards are taking off as viable modes of short-distance transportation. The first toy quadcopters were little more than annoyances, but their bigger cousins, combined with specialized software, are transforming both filmmaking and surveying work.

For now, what makes Shenzhen unique as a manufacturing hub is its ability to accommodate everything from the serious to the silly, from the experimental to the sustainable, from devices that alleviate poverty to gadgets that grab headlines. When we asked Zhang about the cultural DNA embedded in the products coming out of Shenzhen, he replied, "Products made in Shenzhen have a hundred percent Chinese DNA and a hundred percent Western DNA. A hundred percent Western because, even if they're made in China, they are consumed by the world."

An Xiao Mina leads the product team at Meedan, a social technology company, and is the author of Memes to Movements: How the World's Most Viral Media Is Changing Social Protest and Power.

Jan Chipchase is the founder of Studio D, a research, design, and strategy consultancy with offices in San Francisco and Tokyo.

Written with additional thanks to Studio D research intern Amber Tan and translator Vivian Qin. Research for this article was partly funded by the Hong Kong Design Trust, a project of Hong Kong Ambassadors of Design.


Electric
ave

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CHINA'S PAST ATTEMPTS TO GET INTO THE CAR INDUSTRY WERE FAILURES, BUT ELECTRIC CARS HAVE OPENED UP A PROMISING NEW PATH.

BY JORDYN DAHL

After the Cultural Revolution of the 1960s and '70s crippled China's economy, the country began to open its markets to the outside world. The aim was to bring in technological know-how from abroad that domestic firms could then assimilate. By the early '80s, foreign automakers were allowed in on the condition that they form a joint venture with a Chinese partner. These Chinese firms, by working with foreign companies, would eventually gain enough knowledge to function independently.

Or so the theory went. Chinese-produced cars subsequently flooded the market, but they were largely cheap copycats—they looked like foreign-made cars, but the engines weren't as good. Carmakers in the US and Europe had too much of a head start for China to catch up.

The only way to outdo the rest of the world, then, was to bet on a whole new technology. Enter electric vehicles, which require less mechanical complexity and rely more on electronic prowess. A Chevrolet Bolt's electric engine contains just 24 moving segments, according to a tear-down performed by consulting company UBS. In comparison, a Volkswagen Golf's combustion engine has 149. Meanwhile, China already had an electronic manufacturing supply chain in place from its

years of producing the world's batteries, phones, and gadgets.

Now the Chinese government is embracing the shift from combustion to electric engines in a way no other country can match. It's made electric vehicles one of the 10 pillars of Made in China 2025—a state-led plan for the country to become a global leader in high-tech industries—and enacted policies to generate demand. Since 2013, almost 500 electric-vehicle companies have launched in China to meet the government's mandate and to cash in on subsidies designed to generate supply.

For consumers, the government promised one of the most difficult things to obtain in China's metropolises: a license plate. To combat pollution, the number of license plates issued each year is strictly limited. Beijing awards them through a lottery, but the chance of getting one in any given year is now 0.2%. Shanghai sells them at an auction with prices of over $14,000, more than the price of many domestically produced cars. Electric-vehicle plates are not only faster to get; they're free.

"The world needs a different way of powering the economy," says Bill Russo, CEO of the Shanghai consultancy firm Automobility. "China recognizes it can't be dependent on fossil fuels—it will choke on its own fumes."

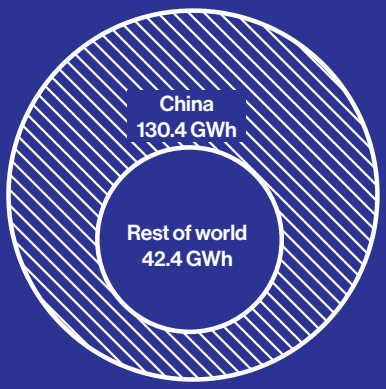
China's breakneck speed has changed the strategies of traditional auto manufacturers. Many are now basing their global strategy for electrification on China's industrial policy, but the momentum behind China's companies is hard to match—and that's a threat to the bottom line for Ford, General Motors, and European carmakers.

"The industry has always been dominated by Japan, the Europeans, and the US," says Jonas Nahm, an assistant professor of energy, resources, and environment at the Johns Hopkins School of Advanced International Studies. "The center of gravity is shifting very rapidly. I don't think anyone has figured out a good response to it yet."

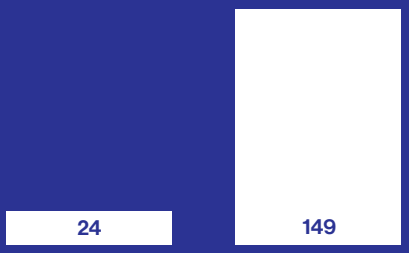
Jordyn Dahl, a freelance writer based in San Francisco, lived in Beijing from 2013 to 2018.

BIG BATTERY PLANS

China has three times as many planned battery plants as the rest of the world combined

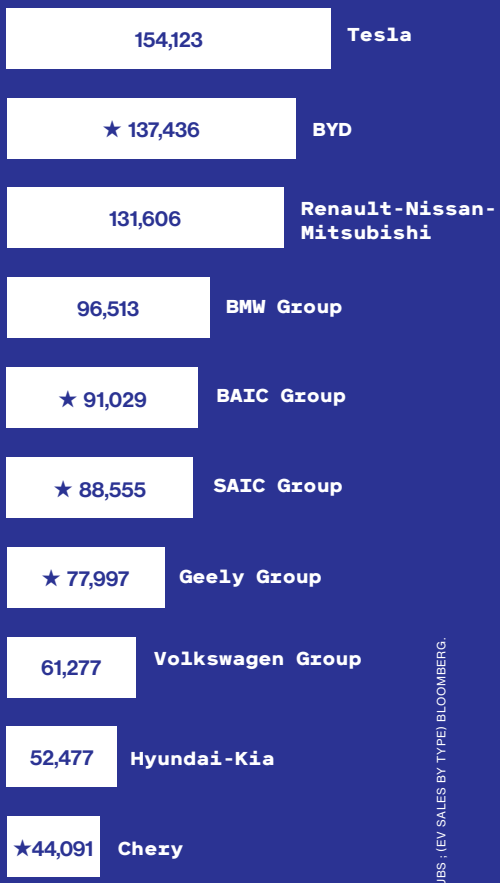


FEWER MOVING PARTS = EASIER TO MAKE



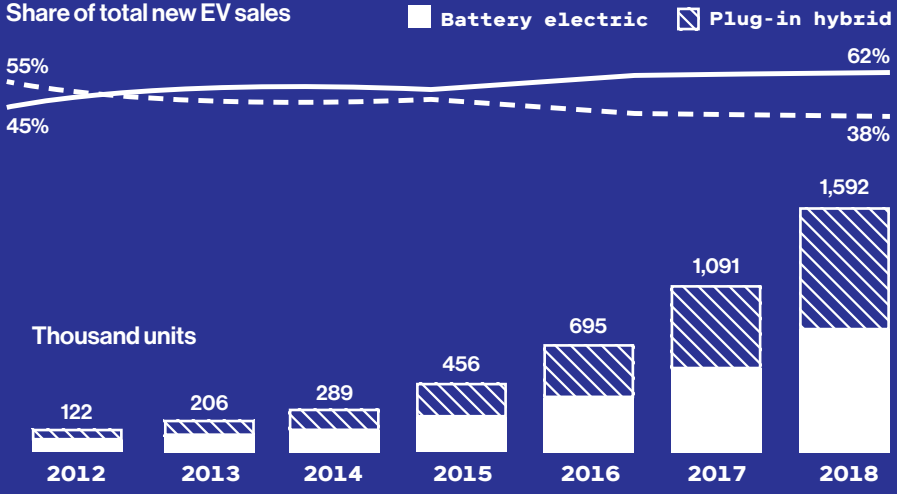
CHINA HAS 5 OF THE TOP 10 EV COMPANIES IN THE WORLD

(Cars sold in 2018 as of September. ★ denotes Chinese company.)



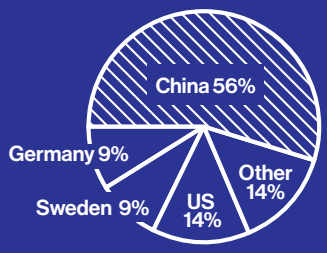
GLOBAL PASSENGER EV SALES BY TYPE

Share of total new EV sales



SOURCES: (BATTERY PLANS) BLOOMBERG ; (TOP EV COMPANIES) INSIDE EVS ; (MOVING PARTS) UBS ; (EV SALES BY TYPE) BLOOMBERG.

Where are lithium-ion batteries made?



2020 forecast from The Wall Street Journal

$14,000
Cost of a license plate for an internal-combustion car in Shanghai

$0
Cost of an electric-vehicle plate in Shanghai

6
Number of cities in China that accounted for 21% of global EV sales in 2017
Bloomberg

487
Number of EV companies that have launched in China since 2013
Bloomberg

A short drive across the Pacific

SELF-DRIVING CARS NEED THE US AND CHINA TO JUST GET ALONG ALREADY.

BY
JEFF DING

The relationship between the US and China has been chilly lately. After credible accusations that China stole intellectual property, and subsequent tariff squabbles, any cross-border investments in areas like AI or computing are under scrutiny, and rightly so.

And then there are self-driving cars.

Automated vehicles embody a contrary trend, where the companies most likely to succeed will be the ones adept at operating in both countries. Why? Because if you want to build a self-driving car, you'll need to go to California to recruit people with knowledge in AI and lidar tech, but you'll also want access to China's faster commercialization, its tough road conditions, and its massive market. To win, you need to be comfortable in both places.

One company that fits this description is Roadstar.ai—headquartered in Shenzhen but with an office in Cupertino, California, where it built its first car. I visited the company's Cupertino office recently and found a place where conversations in English, Chinese, and "Chinglish" take place in a kitchen where the offerings included Taiwanese beef jerky and corn tortillas.

I rode a Roadstar car called Hui around Cupertino, where pedestrians mostly walk on the sidewalk and drivers mostly follow traffic rules. This is very different from navigating China's multi-level, multi-junction interchanges, which Chinese motorists, bus and truck drivers, and pedestrians alike see more as a battlefield than merely a way to get from here to there. Liang Heng, Roadstar's CTO and cofounder, told me China's incredibly complicated traffic conditions give the company a more diverse data set to train the algorithms for autonomous driving.

Roadstar's three cofounders were all born in China and came to the US for PhD programs, then stayed in the Bay Area to work at leading companies in the autonomous-driving field, including Google, Tesla, and Baidu USA. Baidu's driverless-car unit in Sunnyvale, California, where the Roadstar cofounders' paths ultimately overlapped, has strong connections to both the US and China. Roadstar's strategy of operating at the intersection of California and China is in many ways an imitation of Baidu's.

Pony.ai and WeRide are two other Chinese self-driving-car upstarts that have headquarters in Silicon Valley. Both Pony's cofounders, James Peng and Tiancheng Lou, and WeRide's founders, Wang Jing and Tony Han, all previously worked at Baidu.

"California is the R&D center and China is the place where the rubber meets the road," says Michael Dunne, CEO of ZoZo Go, an advisory firm focused on the electric-autonomous market. "It's just a beautiful formula for success."

Jeff Ding is a PhD candidate in international relations at the Governance of AI Program, University of Oxford.

The Sophon AI chip is
designed by Bitmain,
a Beijing-based company.

The chip leap

forward

China has struggled for decades to build a competitive semiconductor industry. The era of artificial intelligence may offer an unprecedented opening.

By Will Knight

Donald Trump is speaking Mandarin.

This is happening in the city of Tianjin, about an hour's drive south of Beijing, within a gleaming office building that belongs to iFlytek, one of China's rapidly rising artificial-intelligence companies. Beyond guarded gates, inside a glitzy showroom, the US president is on a large TV screen heaping praise on the Chinese company. It's Trump's voice and face, but the recording is, of course, fake—a cheeky demonstration of the cutting-edge AI technology iFlytek is developing.

Jiang Tao chuckles and leads the way to some other examples of iFlytek's technology. Throughout the tour, Tao, one of the company's cofounders, uses another remarkable innovation: a hand-held device that converts his words from Mandarin into English almost instantly. At one point he speaks into the machine, and then grins as it translates: "I find that my device solves the communication problem."

iFlytek's translator shows off AI capabilities that rival those found anywhere in the world. But it also highlights a big hole in China's plan, unveiled in 2017, to be the world leader in AI by 2030. The algorithms inside were developed by iFlytek, but the hardware—the microchips that bring those algorithms to life—was designed and made elsewhere. While China manufactures most of the world's electronic gadgets, it has failed, time and again, to master the production of these tiny, impossibly intricate silicon structures. Its dependence on foreign integrated circuits could potentially cripple its AI ambitions.

However, AI itself could change all that. New types of chips are being invented to fully exploit advances in AI, by training and running deep neural networks for tasks such as voice recognition and image processing. These chips handle data in a fundamentally different way from the silicon logic circuits that have defined the cutting edge of hardware for decades. It means reinventing microchips for the first time in ages.

China won't be playing catch-up with these new chips, as it has done with more conventional chips for decades. Instead, its existing strength in AI and its unparalleled access to the quantities of data required to train AI algorithms could give it an edge in designing chips optimized to run them.

China's chip ambitions have geopolitical implications, too. Advanced chips are key to new weapons systems, better cryptography, and more powerful supercomputers. They are also central to the increasing trade tensions between the US and China. A successful chip industry would make China more economically competitive and independent. To many, in both Washington and Beijing, national strength and security are at stake.

> A more advanced chip industry will help China realize its dream of becoming a true technology superpower.

Silicon visions

On the outskirts of Wuhan, a sprawling city a few days' cruise up the Yangtze from Shanghai, stands a factory that would span several football fields. It belongs to Tsinghua Unigroup, a state-backed microchip manufacturer. By the end of 2019, the factory will be producing silicon wafers that will then be cut into advanced memory chips.

Tsinghua Unigroup aims to expand the Wuhan facility to three times its current size, at a total cost of $24 billion. It's developing two similar sites, one along the Yangtze in Nanjing and another further west in Chengdu, at similar cost. They will be the largest and most sophisticated chip factories ever built by a Chinese company.

It's all part of an effort by China to drag its chipmaking industry forward. In 2014, the government established the National Integrated Circuits Industry Investment Fund, a subsidy program that plans to raise $180 billion from local-government-backed funds and state-owned enterprises. A year

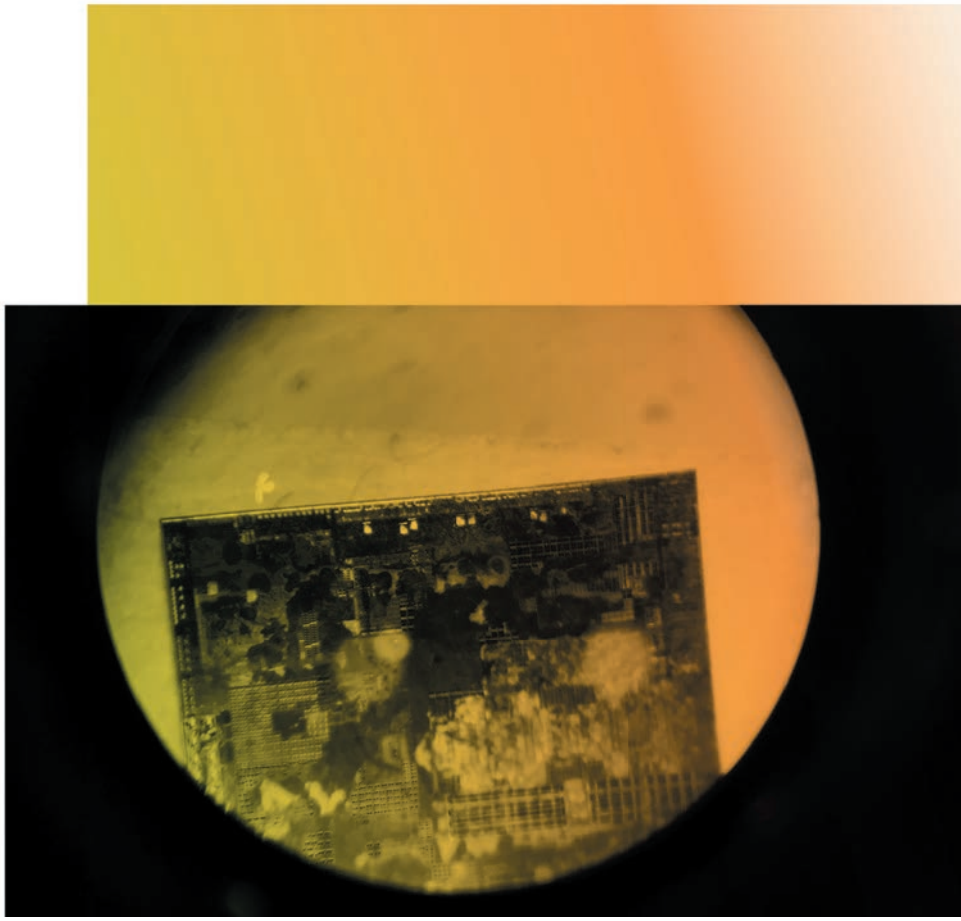
later, it released Made in China 2025, a sweeping blueprint for upgrading China's entire manufacturing industry. This set the hugely ambitious goal of producing $305 billion worth of chips per year and meeting 80% of domestic demand for chips by 2030, up from $65 billion and 33%, respectively, in 2016. Today global production stands at $412 billion.

There is still a long way to go. China is the world's largest and fastest-growing market for semiconductors, but no Chinese chipmaker has broken into the top 15 globally in terms of sales. Advanced chips are primarily made by companies from the US, Taiwan, Japan, South Korea, and Western Europe. China's big economic rival, the US, accounts for about half of global sales and half of China's chip imports.

Beijing has been trying to build a powerful microchip industry for a long time. Researchers developed China's first transistor not long after the device was invented in the US at the end of the 1950s. But the country fell behind as its universities and businesses went through the turmoil of the Cultural Revolution. In the 1960s, as the semiconductor industry began ramping up in Silicon Valley and Moore's Law was articulated, China's fledgling chip industry lay in ruins.

By the time the Chinese economy opened up in the 1980s, it was too late. Chipmakers partnered with foreign firms, but the manufacturing equipment they imported became outdated quickly, and they failed to produce even basic chips reliably or in sufficient volume. And even as China's electronics manufacturing took off in the 1990s, bureaucratic missteps and the ready availability of high-quality imported chips stymied further government pushes. No Chinese company could match the decades of expertise at foreign firms like Intel, Samsung, and Taiwan Semiconductor.

Mark Li, an analyst at Bernstein who tracks the chip industry in Asia, estimates that China's most advanced chipmakers are still at least five years behind. Since Moore's Law describes a doubling of chip performance every two years or so, that's a sizable gap. China does have numerous low-end fabs making the relatively simple chips used in smart cards, SIM cards, and even basic phones, but not the kinds of factories needed to produce advanced processors.



State-backed Tsinghua Unigroup showed off a microscope's view of a chip at a recent high-tech expo in Beijing.

Why does China still struggle to make advanced chips when it has become so good at so much else? Basically, because it's incredibly hard. The latest chips have billions of transistors, each with features only a few nanometers in size, crafted at the scale of individual atoms. They are so complex that it isn't possible to take one apart and copy its design, as Chinese entrepreneurs have done with many foreign products. And even if it were possible, it wouldn't provide the expertise required to design and fabricate the next generation.

"Manufacturing involves hundreds, even thousands, of technical challenges," says Yungang Bao, director of the Center for Advanced Computer Systems at the Chinese Academy of Sciences and an expert in microprocessor design. "It will take a long time to catch up."

PREVIOUS SPREAD: IMAGE COURTESY OF BITMAIN; NG HAN GUAN | AP IMAGES

Network effects

Artificial intelligence may change the game.

Deep learning is an AI technique that has proved its power in recent years to do useful things like spotting disease in medical images, teaching self-driving cars to stay on the road, and parsing spoken commands. It works in a fundamentally different way from most software.

Deep learning uses large networks that roughly resemble the multiple layers of neurons in a biological brain. As a network learns a task, a cascade of computations occur in successive layers. The results of each computation alter the connections between each layer and the next; essentially, the network reprograms itself as it runs. Its ability to recognize objects in images isn't the result of step-by-step logic operations, as in conventional programming, but gradually emerges as countless parameters inside the network are tweaked and re-tweaked through exhaustive training.

Researchers realized early on that the chips in game consoles, originally designed to be fast at rendering 3D imagery, are better for deep learning than general-purpose chips. And deep-learning algorithms are still mostly trained using scores of these graphics processing units (GPUs). One of the market leaders for GPUs is Nvidia, which built its business supplying hardware for gamers. But now Intel and others have designed powerful new chips for training deep learning. Even cloud software businesses like Google's and Amazon's are developing bespoke chips designed for their best algorithms.

Similar Chinese initiatives have been announced over the past year. In July, search giant Baidu revealed that it is working on a chip called Kunlun for running deep-learning algorithms in its data centers. And in September, the e-commerce powerhouse Alibaba said it would spin out a new company dedicated to making AI chips. Tellingly, the new company's name is Pingtouge, a nickname for the honey badger, an African animal famed for fearlessness and tenacity.

The timing of the AI boom is fortuitous for China's chipmakers. The deep-learning revolution was gaining speed just as the government's latest chip push got under way. AI chip design is still in its early days, and in this technology—unlike memory and logic circuits—the country is not hopelessly behind.

Cambricon, one of the country's most valuable startups, is selling new chips specially designed for artificial-intelligence cloud applications.

CAMBRICON

Specialized hardware

Kai Yu has already played a significant role in China's AI revolution. A cheerful, bespectacled man who studied neural networks at college in China and Germany in the late 1990s and early 2000s, he founded Baidu's Institute of Deep Learning in 2013,

人工智能正在改变世界

"Artificial intelligence is transforming the world."

as the company became one of the first to bet heavily on AI.

Navigating Beijing's morning traffic in the backseat of a Didi, Yu says the importance of chip hardware quickly became apparent when Baidu started pouring resources into deep learning. In 2015, he says, he suggested that Baidu make a specialized AI chip. But it seemed costly and far outside of the company's expertise. So later that year, Yu left to found his own company, Horizon Robotics.

Horizon is focused on "application-specific" microchips that run pre-trained deep-learning algorithms. It's developing them for self-driving cars and smarter robots. But Yu thinks these chips will be everywhere before long. "If we look back in 10 years," he says, "more than half of the computations on a device will be AI related."

In August, Huawei, China's biggest telecommunications and smartphone company, unveiled a mobile chip, the Kirin 980, that includes a "neural processing unit"—a section of logic designed for deep-learning tasks like image and voice recognition.

In one sense, the chip illustrates a lingering limitation of China's capabilities—it was manufactured by Taiwan's TSMC. But in another, it reflects China's striking progress and ambition. The chip is one of the country's first to include features as small as 7 nanometers. Smaller components make chips faster and more capable, but also a lot harder to design and manufacture, so this a significant coup for Huawei. Designs for the part of the chip optimized for deep learning come from a startup called Cambricon, founded in 2016 by researchers from the Chinese Academy of Sciences. Today Cambricon is valued at $2.5 billion, making it the industry's most valuable startup. In October, Huawei announced another AI chip, called Ascend, that is designed in-house.

Chip on the shoulder

China's chip ambitions have rattled other countries, especially the US. Partly that's because its efforts to gain access to technology have sometimes involved aggressive acquisitions, forced technology transfer, and, allegedly, industrial espionage. Chipmaking is key to military prowess, and the Obama administration sought to block Chinese attempts to acquire US chip technology long before Donald Trump arrived in the White House. It's one of the few issues that unite US politicians.

In April 2018 the US banned one of China's leading tech companies, ZTE, from using US chips because it had broken a ban on selling equipment containing US technology to Iran and North Korea. In October, the US said the memory-chip maker Fujian Jinhau, a company accused of stealing trade secrets, would need a special license to buy US-made components. These restrictions may partly be a response to property theft and unfair trade, but they also look like an effort to slow China's chipmaking progress.

Yet a trade war may only hasten China's ascent. "People in China realized that the US can easily stop their progress," says Bao at the Chinese Academy of Sciences. "It will probably speed things up."

However fast it happens, China's march to advanced chipmaking is all but unstoppable. No true superpower can afford to outsource technology that is so critical to both its economic growth and its military security. And after decades of playing catch-up, the country is finally seeing opportunities to establish mastery of the field.

In Tianjin, Tao is explaining that iFlytek is thinking about designing its own chips, to improve the performance of its electronic translators. Just then, the AI-generated version of Trump speaks up. 人工智能正在改变世界 (*Réngōng zhìnéng zhèngzài gǎibiàn shìjiè*), he says: "Artificial intelligence is transforming the world."

Will Knight is MIT Technology Review's senior editor covering AI.

artist: **Lu Yang**

project:
Delusional Mandala

Lu relies on Western streaming services like Vimeo to distribute her work, and she is fond of saying that she lives on the internet. *Delusional Mandala* is a series in which Lu inserts a 3D-scanned avatar of herself into scenarios that oscillate between sacred and profane, raising compelling questions about the nature of selfhood.

THE ART OF TECH

2 OF 3

Identity

Anxieties about economic advantage, national security, and censorship tend to dominate the West's conversation about technology in China. But Chinese artists have a different set of concerns about technology's ramifications. Shanghai-based artist **Miao Ying** references censorship in some of her works. But she is less interested in taking a stand against the Chinese government's regulation of the internet than in highlighting the unique cultural tics that take shape under those strictures. Much of her work deals with her concept of the "Chinternet"—a break with Western norms that supplies fertile ground for new ideas and identities to grow. Fellow Shanghai artist **Lu Yang** likewise plays with the intersection between technology and identity: her outlandish digital avatars evade categorization along national, racial, or gender lines, and thus afford glimpses of a digital, post-human future. *—Josh Feola*

artist: **Lu Yang**

project: ***Electromagnetic Brainology***

Lu does not see technology as an end in itself, but as a tool of exploration. "If art comes from life, then there is no way to distinguish current technology and art," she says. Many of her videos, like 2017's *Electromagnetic Brainology*, weave neurology, religion, and pop culture into a hybrid, personalized aesthetic identity.

artist: **Miao Ying** project: ***God, Goddess, and Godfather***

In this work, Miao pokes fun at the hallowed status that Alibaba founder Jack Ma has attained among Chinese netizens. Entrepreneurs like Ma who have amassed godlike fortunes in the last decade have become cultural icons on Chinese social media, kick-starting new cults of personality and identity.

COURTESY OF THE ARTIST (LU YANG); COURTESY OF MADEIN GALLERY

Satellite images: CSIS Asia Maritime Transparency Initiative/ DigitalGlobe

Fiery Cross Reef, an artificial island built by China, boasts a two-mile-long runway, massive harbor, and elaborate military fortifications.

NATION BUILDING

How China became the world's most prolific maker of artificial islands.

By **VINCE BEISER**

Fifteen miles out on the water south of Biloxi, Mississippi, below a cloudless sky, a foaming torrent of gray-black slurry gushes into a ship. Every three seconds, another truckload's worth of salt water and sand, siphoned from the bottom of the Gulf of Mexico, pours into the *Ellis Island*'s vast, open cargo hold, called a hopper. The ship is gargantuan—the biggest such dredge ever built in the United States. Its progress is, by design, slow. It is hauling a pair of 30-ton drag heads, studded with steel teeth, which scrape along the sandy sea bottom. Twin pipes, each three feet (90 centimeters) in diameter, connect the drag heads to giant pumps on the ship's deck. The pumps suck slurry into the hopper, which slowly fills with roiling gray soup, speckled with muculent, softball-size bubbles.

"We call ourselves dirt merchants," Gabriel Cuebas, the *Ellis Island*'s captain, told me when I visited on a hot October day. His ship is 433 feet (132 meters) long—a good bit longer than an American football field and about half the length of an aircraft carrier. Twin yellow cranes perch on either side of the deck. Their metal bulk towers over a maze of catwalks and pipes that surround the hopper.

It takes several hours for the hopper to fill with slurry. Once that is done, enormous winches haul up the drag heads, and the ship sets course toward the mainland. An hour or so later, the *Ellis Island* drops anchor several miles offshore, in water deep enough for its 30-foot draft. An assembly that looks like an eyeless robotic sea serpent bobs in the waves. Crew members get a rope around the serpent's head and winch it out of the water. They connect the serpent to a pipe leading from the hopper. The ship's pumps kick in again, pulling slurry back out of the hopper and shooting it down a mile of pipe to a floating booster station, where more pumps will usher it along. The sand will travel through almost five miles (eight kilometers) of pipe before it is finally blasted onto the shore of Ship Island.

Ship Island is, for the moment, actually two islands. What was originally its center was eroded by hurricanes: Camille in 1969 and Katrina in 2005. (It was spared the worst of 2018's Hurricane Michael.) The US Army Corps of Engineers, the federal agency charged with maintaining America's waterways, has hired the *Ellis Island* to help rebuild the eight-mile-long island, an important bulwark against increasingly severe storm surges.

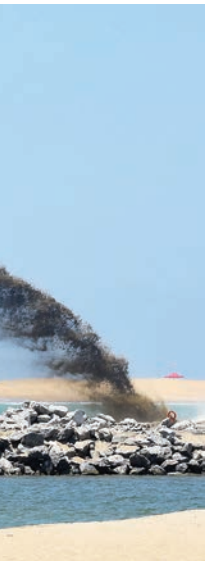
The Wan Qing Sha, a trailing suction hopper dredger, helps build a new city off the coast of Colombo as part of a massive Chinese infrastructure project, the largest foreign investment in Sri Lanka's history.

Once this load of sand has been discharged, the *Ellis Island* will head back out for another, and then another, around the clock, day after day. The whole job will take about a year, during which a relay of ships will move enough sand to bury the real Ellis Island 50 yards deep: 7 million cubic yards (5.4 million cubic meters) of it. The total cost of rebuilding Ship Island, to be paid by the federal government, will be some $350 million.

It is a colossal operation. But compared with what China is doing, it's a drop in the ocean.

In China as elsewhere, dredging is used to build protective barriers against the rising seas, as the *Ellis Island* is doing, and to create valuable new real estate. But for China's president, Xi Jinping, it is also an important geopolitical tool. Today, more than ever, dredges have the power to create land where there was none, altering the shapes of coastlines and the contours of countries. No nation has cultivated this power more zealously than China.

In recent years, China has assembled an armada of oceangoing dredges. Some it buys from Japan, Belgium, and the Netherlands. Increasingly, though, China manufactures them itself. China's homemade dredges are not yet the world's largest, nor are they any more technologically advanced than those of other countries, but it is building many more of them than any other country. In the past decade, Chinese firms have built some 200 vessels of ever greater size and sophistication. In 2013, Rabobank, a



ISHARA S. KODIKARA/AFP/GETTY IMAGES

Most plant and animal life on the seven Spratly reefs was destroyed by the mountains of sand dumped atop the coral.

Dutch firm, declared that China's dredging industry had become the biggest in the world, and it has only grown since then. Chinese firms bring in as much revenue from domestic dredging as is accrued in all of Europe and the Middle East combined.

Since 1985, according to Deltares, a Dutch research group, humans have added 5,237 square miles (13,564 sq km) of artificial land to the world's coasts. China is a major—and growing—contributor to that total.

In 2015 alone, China created the equivalent of nearly two Manhattans of new real estate. In recent years, it constructed two artificial islands to support a 34-mile-long bridge that connects Hong Kong with Macao and the Chinese mainland; it opened in October 2018 and is the world's longest sea crossing. Much of that work was carried out by state-owned CCCC Dredging, the world's largest dredging firm. By way of comparison: In 2017, Great Lakes Dredge and Dock, America's biggest, took in an estimated $600 million from dredging operations. CCCC Dredging booked $7 billion.

Manufacturing land is not a new practice. The Dutch have been creating new territory since the 11th century by damming wetlands and pumping them dry. Peter Stuyvesant, the first governor of what would come to be called Manhattan, expanded the island with earth displaced by the construction of buildings and canals. Land reclamation, as the practice is called even when the "reclaimed" land is entirely new, has long gone hand in hand with dredging's other main purpose—clearing paths for ships to travel in.

Today the industry's basic tool is the centrifugal pump. It is something like a blender bisected by a garden hose. A motorized drive shaft spins an impeller. The impeller's spin pulls liquid (and sand) through the pipe. First introduced in the 1860s, these pumps enormously increased the amounts of sediment that can be siphoned from the ground under the sea. They also make it possible to pump the stuff through miles of pipeline to distant destinations.

As steam power gave way to diesel in the late 19th century, the size and power of dredges grew. Developers in Los Angeles used centrifugal pumps to expand the city's port and turn marshlands into seaside real estate. Sediment dredged from underwater built Boston's Back Bay, as well as large portions of Marseilles, Mumbai, and Hong Kong.

Beginning in the 1970s, oil-exporting countries in the Persian Gulf plowed their surging wealth into developing huge new ports, which spurred dredging companies to bring larger, mightier ships to market. For coastal megalopolises long on population but short on waterfront, land reclamation offers a way to add room. Hong Kong and Osaka, Japan, both built new international airports on artificial islands in the 1990s. Many of the world's largest artificial islands are either in the Middle East, such as Dubai's famous palm-tree-shaped islands, or off the coast of Japan. But that is changing.

The Chinese government declared dredging a "priority growth area" in 2001, as part of a push to increase China's maritime power. At the time, the country's dredging fleet consisted of aging, outdated ships. Chinese companies were capable of building only relatively small vessels. With the government's support and investment, capabilities boomed. In the past 15 years, Chinese companies have built scores of the main types of giant dredges: trailing suction hopper dredgers—"trailers" for short—and cutter suction dredgers.

Trailers like the *Ellis Island* gather sand while on the move. Their drag heads break up loosely compacted sea-bottom sands, which are then vacuumed up and stored in the ship's hoppers for transport. In 1965, the biggest such dredges could hold about 6,500 cubic yards of material. That number more than tripled by 1994; by now, it has grown nearly tenfold. The world's two biggest dredges, the *Cristóbal Colón* and the *Leiv Eiriksson*, were built in Spain for Belgium's Jan De Nul Group in 2009 and 2010. They are identical twins. Stood on end, each would rise higher than a 60-story skyscraper. They can carry about four times as much sludge as the *Ellis Island*.

Cutter suction dredgers, meanwhile, anchor in areas where the sea bottom is too hard for trailers. A boom arm capped with a cutter head—a tooth-studded steel ball the size of a wine barrel—protrudes from the bottom of the ship. The ball spins around, tearing up sand, rocks, and whatever else it finds on the seabed, while a suction line behind it hoovers up the grains. The material is then pumped onto a barge, or sometimes straight into a pipe leading to the land reclamation site. Cutter suction dredgers' might is measured by their installed electrical power, which has also grown exponentially in recent decades. The most potent generate and consume more than 40 megawatts—enough to power 30,000 American homes.

In 2017, CCCC Dredging launched the *Tian Kun Hao*, Asia's biggest cutter suction dredger, which was built entirely in China. It is about the same size as the *Ellis Island*, or about a quarter the size of the Belgian behemoths, and can suck nearly 8,000 cubic yards of sand and other material per hour from depths up to 100 feet.

CCCC Dredging has begun taking on projects overseas, and it now operates in dozens of countries. It has a particular focus on places targeted for Chinese-led port development as part of Xi's Belt and Road Initiative.

China's land reclamation work will have tremendous economic consequences in coming years. Its political consequences are already profound.

The South China Sea is one of the world's busiest shipping routes. What's more, billions of barrels of oil and trillions of cubic feet of natural gas lie under the seafloor. So it's no surprise that every country in the region—China, Taiwan, Vietnam, Brunei, Malaysia, and the Philippines—lays claim to parts of the Spratly Islands, a scattering of rocks and reefs in the middle of the sea, 500 miles due east of Vietnam and 200 miles southwest of the Philippines.

China controls seven naturally occurring Spratly outcroppings (one of which it seized from Vietnam in a 1988 clash that left dozens of soldiers dead). It is using its industrial might to create new facts in the water. Starting in late 2013, the Chinese government set dozens of CCCC Dredging's ships to work. Within 18 months, these ships added nearly 3,000 acres (1,200 hectares) of new land to the Spratlys, enough to fit three copies of New York's Central Park with room to spare.

Almost as soon as the sand was dry, China began turning the new islands into military bases. It installed antimissile weaponry, runways capable of handling military aircraft, structures apparently designed to house long-range surface-to-air missile launchers, and port facilities for warships. China has also built new territory in another tiny collection of South China Sea islands called the Paracels, where it has similarly installed airstrips and missile batteries.

This expansion of Chinese power into the Pacific has alarmed the US as well as China's neighbors. To show it does not recognize the new islands as Chinese territory, the United States has made a point of flying B-52 bombers over them and sending warships to pass close by. For its part, China has landed long-range bombers on its new runways, as a show of force.

Tensions spiked in late September 2018, when the *Lanzhou*, a Chinese destroyer, cut across the bow of the USS *Decatur*, an American destroyer. The *Decatur*'s captain slammed the ship's engines into reverse, averting a collision by only 45 yards—a quarter of the length of his ship. The incident took place just a few miles away from some of the new artificial islands.

It may be too late for other nations to do much about China's artificial-land grab. Admiral Philip S. Davidson, head of the US Indo-Pacific Command, told Congress in April (shortly before assuming his command) that "China is now capable of controlling the South China Sea in all scenarios short of war with the United States."

All that island building has also caused "devastating and long-lasting damage to the marine environment," according to the Hague-based Permanent Court of Arbitration, which rejected China's claim to sovereignty over much of the South China Sea in 2016. Most plant and animal life on the seven Spratly reefs was destroyed by the mountains of sand dumped atop the coral. John McManus, a University of Miami marine biologist, called it "the most rapid rate of permanent loss of coral reef area in human history."

Other land reclamation projects have inflicted similar, albeit smaller-scale, damage. They have destroyed or damaged coral reefs and oyster and seagrass beds in Dubai, Bahrain, and other Gulf countries, as well as killing marine life. In the US, dredges are required to make sure they're not sucking up turtles and other sea creatures; if they do, they have to stop work until they address the problem. Environmental concerns are one reason why, while China is feverishly building new land, land reclamation in the US is just what it sounds like—confined almost exclusively to counteracting the erosion of previously existing land. "In Bahrain, if we found a turtle we'd just throw it back over the side," says Brian Puckett, a Great Lakes executive who oversees the Ship Island project.

Puckett is proud to show off pictures of the islands he helped create for real estate developers in the Persian Gulf. "It's amazing to be able to show them to people on Google Earth and say, 'I built that,'" he says. "That was part of the reason I came to work with Great Lakes. I want to work on projects that are important."

Island building, as China has shown, is one of the most important projects there is. Today, geopolitical power goes not only to those who control territory but to those who can manufacture it.

Vince Beiser is the author of The World in a Grain: The Story of Sand and How It Transformed Civilization. Reporting for this article was supported by the Pulitzer Center on Crisis Reporting.

Ships congregate just northeast of Fiery Cross Reef.

Almost as soon as the sand was dry, China began turning the new islands into military bases.

CSIS ASIA MARITIME TRANSPARENCY INITIATIVE/DIGITALGLOBE

NUCLEAR POWER, S

WATCH DEATH

ONCE NUCLEAR'S STRONGEST BOOSTER, CHINA IS GROWING WARY ABOUT ITS COST AND SAFETY.

BY PETER FAIRLEY

"Most

beautiful wedding photos taken at a nuclear power plant" might just be the strangest competition ever. But by inviting couples to celebrate their nuptials at the Daya Bay plant in Shenzhen and post the pictures online, China General Nuclear Power (CGN), the country's largest nuclear power operator, got lots of favorable publicity.

A year later, the honeymoon is over.

For years, as other countries have shied away from nuclear power, China has been its strongest advocate. Of the four reactors that started up worldwide in 2017, three were in China and the fourth was built by Beijing-based China National Nuclear Corp. (CNNC) in Pakistan. China's domestic nuclear generation capacity grew by 24% in the first 10 months of 2018.

The country has the capacity to build 10 to 12 nuclear reactors a year. But though reactors begun several years ago are still coming online, the industry has not broken ground on a new plant in China since late 2016, according to a recent World Nuclear Industry Status Report.

Officially China still sees nuclear power as a must-have. But unofficially, the technology is on a death watch. Experts, including some with links to the government, see China's nuclear sector succumbing to the same problems affecting the West: the technology is too expensive, and the public doesn't want it.

The 2011 meltdown at Japan's Fukushima Daiichi plant shocked Chinese officials and made a strong impression on many Chinese citizens. A government survey in August 2017 found that only 40% of the public supported nuclear power development.

The bigger problem is financial. Reactors built with extra safety features and more robust cooling systems to avoid a Fukushima-like disaster are expensive, while the costs of wind and solar power continue to plummet: they are now 20% cheaper than electricity from new nuclear plants in China, according to Bloomberg New Energy Finance. Moreover, high construction costs make nuclear a risky investment.

And gone are the days when nuclear power was desperately needed to meet China's soaring demand for electricity. In the early 2000s, power consumption was growing at more than 10% annually as the economy boomed and manufacturing, a heavy user of electricity, expanded rapidly. Over the past few years, as growth has slowed and the economy has diversified, power demand has been growing, on average, at less than 4%.

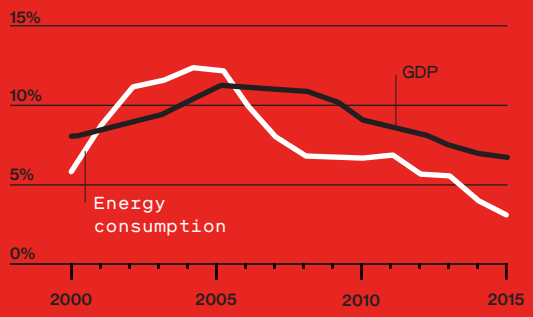
China's disenchantment with nuclear power corresponds with an overall decline in nuclear generation elsewhere in the world. Utilities are retiring existing plants and have stopped building new ones. If China, too, gives up on nuclear, it could sound the death knell for a steady, carbon-free energy source that many see as crucial to slowing climate change.

Fukushima changed everything

China's energy planners launched its nuclear industry in the 1980s with the construction of plants like Daya Bay. In 2005 the country began a massive building spree that was intended to solve persistent energy shortages and combat worsening air pollution from the country's numerous coal plants. By 2009, government planners expected 2020 nuclear capacity to be 10 times what it was in 2005.

Then the Fukushima disaster happened. China's leaders watched in shock as the biggest utility in one of the world's most advanced industrial countries proved powerless to prevent a series of meltdowns. They knew that if a similar accident occurred in China,

China's overall appetite for energy is slowing as the economy cools and shifts away from manufacturing
(annual growth rates)

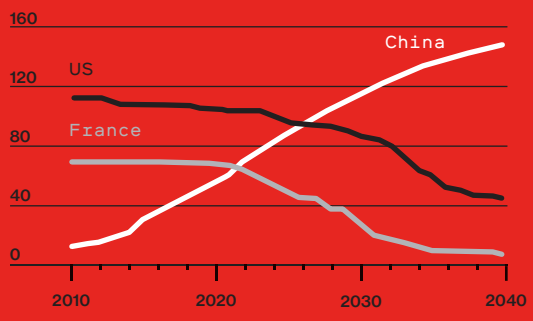


SOURCE: US ENERGY INFORMATION ADMINISTRATION

China has the most nuclear reactors under construction (December 2018)

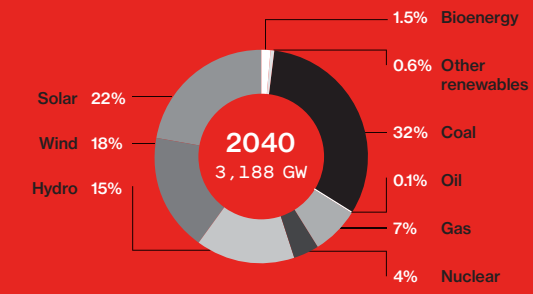
SOURCE: INTERNATIONAL ATOMIC ENERGY AGENCY

The IEA had expected China to soon lead the world in nuclear capacity (gigawatts)



SOURCE FATIH BIROL/INTERNATIONAL ENERGY AGENCY

In China's expected energy future, nuclear is still a small slice



SOURCE: INTERNATIONAL ENERGY AGENCY

Rising costs at a pair of gas-cooled reactors prompted plans for a further 18 reactors to be canceled.

the damage wouldn't be limited to the explosion and nuclear fallout. Such an event would call into question the government's competence. "If an event like Fukushima punctures that image of competence, that's very, very consequential," says William Overholt, a China expert at Harvard University's Kennedy School of Government. "That would delegitimize the regime."

Within days of Fukushima, nuclear reactor construction in China was frozen. When building resumed months later, after a wave of inspections, Beijing insisted that future nuclear power projects adopt more advanced designs with extra safety features.

The damage to public confidence, however, had already been done. In 2013 over a thousand people assembled in Jiangmen, east of Hong Kong, to decry a planned uranium fuel plant. Within days the state-run project was scrapped. In 2016 local officials suspended preliminary work on a site in Lianyungang, in northeastern Jiangsu province, after an uproar caused by revelations that it might host a recycling plant for spent nuclear fuel. In the wake of that protest, China's State Council amended its draft regulations on nuclear power management, requiring developers to hold public hearings before siting projects.

Sticker shock

Last June two of the world's most advanced reactors began operating in China: a US-designed AP1000 and a French-German EPR. In theory, these reactors are at greatly reduced risk of a Fukushima-style accident. At the Japanese plant, tsunami waves swamped the backup generators needed to keep coolant pumps running, and the catastrophic loss of coolant caused three of the plant's six reactors to melt down. The AP1000 design stores water above the reactor that can be gravity-fed to keep it cool if the pumps fail. The EPR reactors employ multiple redundant generators and cooling systems to lower meltdown risk.

But adding safety adds cost. At 52.5 billion yuan ($7.6 billion) for an AP1000 plant with the typical configuration of two reactors, the construction cost is nearly double that of the conventional technology commonly used in China. Wenke Han, a former head of the Energy Research Institute, an arm of the powerful National Development and Reform Commission that plans China's economy, calls nuclear power "very expensive." He adds, "Nuclear power in China has begun to face price competition, and will certainly face more competition in the future."

Coal remains the cheapest source of power in China, but grid operators face demands from the government to use more renewable energy to limit air pollution. With pressure from both directions, even the nuclear plants now operating are underutilized. On average they used 81% of their generating capacity in 2017, 10% less than five years earlier, making the electricity they produce even more expensive.

Dwindling options

The government has lately said little about nuclear policy. Its official target, last updated in 2016, calls for 58 gigawatts of nuclear generating capacity to be installed by 2020 and for another 30 GW to be under construction. All experts agree China won't reach its 2020 goal until 2022 or later, and pre-Fukushima projections of 400 GW or more by midcentury now look fanciful. Han says he is betting that after the country builds the 88 GW in its 2020 plan, it will move on to other energy sources.

Others believe that China will continue building reactors but at a slower pace than in the past. The country is developing its own advanced design, the Hualong One, and may want to protect the nuclear industry, including its nascent efforts to export the new reactor. CNNC is building two in Pakistan, and CGN is seeking design approval in the UK. CNNC is also building two at its Fuqing power plant in southeastern Fujian province. Construction began in 2015, and CNNC says it will have one reactor operating in 2019, ahead of schedule.

If the Hualong One proves too expensive, China's lingering nuclear hopes will be pinned to its advanced-reactor program—an effort to develop a new generation of technologies that include high-temperature gas-cooled reactors, designs cooled with sodium metal or salt, and smaller versions of pressurized-water reactors. These various designs are meant to be cheaper to build and operate—and much safer—than conventional reactors.

But so far there is little evidence that any of them will solve nuclear's problems. A sodium-cooled reactor completed near Beijing in 2011 has had familiar technical glitches such as problems in its coolant systems. And the rising cost of a pair of high-temperature gas-cooled reactors nearing completion at Shandong Province's Shidao Bay ended plans for a further 18 such reactors at the site.

There's always the possibility of a breakthrough that would make nuclear safe and cheap enough to compete with renewables and coal. But even China's nuclear giants are hedging their bets. Both CGN and the state-owned firm funding China's AP1000 investments rank among the world's top 10 renewable-power operators.

Shifting toward renewables and away from nuclear may be a sound business strategy for these companies. But it could mean one less carbon-free option for a world facing the threat of climate change. If China's nuclear ambitions wind down, it may be the nail in the coffin for the technology's viability elsewhere.

Peter Fairley is a freelance energy journalist based in San Francisco and Victoria, BC.

PREVIOUS SPREAD: AP IMAGES

China vs. the US: Who wins and who loses

Yasheng Huang, author of the 2008 book *Capitalism with Chinese Characteristics*, is an expert on entrepreneurship in China.

By Will Knight
Portrait by Tony Luong

Born in Beijing and educated at Harvard, Yasheng Huang, a professor at MIT's Sloan School of Management, is a keen observer of China's entrepreneurial efforts and the role the government has played in the country's remarkable growth. Will Knight, a senior editor at MIT Technology Review, recently talked with Huang about the country's changing technology scene.

In what areas of technology is China ahead?
In AI and big data, China is surging ahead, there's no doubt. These are areas compatible with the government's politics and things like its "social credit system."

People also talk about life sciences. To some extent, that's developing fast for similar reasons as AI. You just plunge ahead without privacy complaints, without safeguards, regulatory constraints.

In a very crude sense, you can develop science very fast without constraints.

[In] anything that requires a lot of capital commitment, and that's in line with the political objectives, you can expect China to move forward. So, for example, in quantum computing and maybe even microchips.

How much does China depend on the US for finance, talent, and IP?
China is not that dependent on the US for financing, and it is exporting talent to the US. In terms of intellectual property, we just don't know. There's a perception that China parrots US IP, and I think as a general description that's probably right. But China is also producing some IP as well. I think China is, however, very dependent not just on the US but also on Japan, South Korea, and other countries for critical, key components in their manufacturing.

Who is losing more from the trade war?
If I must give an answer, I would argue China.

Even though the Chinese economy is growing at a higher level, it is trending downwards. Whereas the US economy is trending upwards. There is concern about overheating in the US economy. But to some extent, a trade war acts as a brake on an overheating economy. In the Chinese case, it's like taking away the fuel from a fire that is diminishing. Whether the US has the tolerance, that's a separate question. It could be that the US is losing less, but then the political system here is more sensitive.

Will tightening immigration rules help protect America's intellectual property?
Those moves I see as more damaging to the US than China. If you look at MIT, a lot of great research is done together with Chinese graduate students and Chinese professors. Once you stop that, that's going to have a big impact on cutting-edge research.

Their rationale is that there are Chinese spies. I'm not going to say there are none. But that's like saying "There are criminals, therefore we should ban human beings." It's a law-and-order issue. You should step up vigilance and controls, rather than stopping Chinese from coming here.

Why hasn't China's economic boom been accompanied by political reform?
There are really two things going on. One is the values of the Chinese people, the norms, and I think the evidence is very clear that those are changing—maybe not toward democracy, but toward more openness. Then there is the politics—the leadership and the government.

Economics can predict the value changes, but I don't think it can be that deterministic of who becomes the president. Look at this country. Trump became president, and who would predict that in terms of economics? Politics has its own dynamics.

How supportive is the government for entrepreneurs?
It is the natural inclination of the government not to support the private sector. I think it takes a substantial reduction of economic growth for them to fundamentally change the way they do things. It's not just a matter of supporting, either. It's a matter of really taking the government out of the private sector, at least drawing a clear line between the government and the private sector. That's something they don't want to do.

Dreams of a global grid

Are China's next-generation power lines a clean-energy play or a global power move?

By **JAMES TEMPLE**

Illustration by
FRANZISKA BARCZYK

Early in February 2018, Chinese workers began assembling a soaring red-and-white transmission tower on the eastern edge of Anhui province. They straddled metal tubes as they tightened together latticed sections suspended high above the south bank of the Yangtze River.

The men were erecting a critical section of the world's first 1.1-million-volt transmission line, at a time when US companies are struggling to build anything more than 500,000 volts. Once the government-owned State Grid Corporation of China completes the project this year, the line will stretch from the Xinjiang region in the northwest to Anhui in the east, connecting power plants deep in the interior of the country to cities near the coast.

The transmission line will be capable of delivering the output of 12 large power plants over nearly 2,000 miles (3,200 kilometers), sending 50% more electricity 600 miles farther than anything that's ever been built. (Higher-voltage lines can carry electricity over longer distances with lower transmission losses.) As one foreign equipment provider for the project boasts, the line could ship electricity from Beijing to Bangkok—which, as it happens, only hints at State Grid's rising global ambitions.

The company initially developed and built ultra-high-voltage lines to meet growing appetites for energy across the sprawling nation, where high mountains and vast distances separate population centers from coal, hydroelectric, wind, and solar resources. But now State Grid is pursuing a far more ambitious goal: to stitch together the electricity systems of neighboring nations into transcontinental "supergrids" capable of swapping energy across borders and oceans.

These massive networks could help slash climate emissions by enabling fluctuating renewable sources like wind and solar to generate a far larger share of the electricity used by these countries. The longer, higher-capacity lines make it possible to balance out the dimming sun in one time zone with, say, wind, hydroelectric, or geothermal energy several zones away.

Politics and bureaucracy have stymied the deployment of such immense, modern power grids in much of the world. In the United States, it can take more than a decade to secure the necessary approvals for the towers, wires, and underground tubes that cut across swaths of federal, national, state, county, and private lands—on the rare occasion when they get approved at all.

"A long-distance interconnected transmission grid is a big piece of the climate puzzle," says Steven Chu, the former US energy secretary, who serves as vice chairman of the nonprofit that State Grid launched in 2016 to promote international grid connections. "China is saying, 'We want to be leaders in all these future technologies,' instead of looking in the rearview mirror like the United States seems to be doing at the moment."

"China is saying, 'We want to be leaders in all these future technologies,' instead of looking in the rearview mirror like the United States seems to be doing at the moment."

But facilitating the greater use of renewables clearly isn't China's only motivation. Transmission infrastructure is a strategic piece of the Belt and Road Initiative, China's multitrillion-dollar effort to build development projects and trade relationships across dozens of nations. Stretching its ultra-high-voltage wires around the world promises to extend the nation's swelling economic, technological, and political power.

23,000 MILES OF WIRES

State Grid is probably the biggest company you've never heard of, with nearly 1 million employees and 1.1 billion customers.

Last year, it reported $9.5 billion in profit on $350 billion in revenue, making it the second-largest company on Fortune's Global 500 list.

State Grid is already the biggest power distributor in Brazil, where it built its first overseas ultra-high-voltage line. The company has also snapped up stakes in national transmission companies in Australia, Greece, Italy, the Philippines, and Portugal. Meanwhile, it's pushing ahead on major projects in Egypt, Ethiopia, Mozambique, and Pakistan and continues to bid for shares in other European utilities.

"A lot of Chinese companies are very ambitious in spreading overseas," says Simon Nicholas, coauthor of a report tracking these investments by the Institute for Energy Economics and Financial Analysis, a US think tank. "But State Grid is on another level."

State Grid was created in late 2002, when the government broke up a massive monopoly, the State Power Corporation of China, into 11 smaller power generation and distribution companies. That regulatory unbundling was designed to introduce competition and accelerate development as the nation struggled to meet rising energy demands and halt recurrent blackouts. But State Grid was by far the larger of two resulting transmission companies, and it operates as an effective monopoly across nearly 90% of the country.

In 2004, the Communist Party handpicked Liu Zhenya, the former head of Shandong province's power bureau, to replace the retiring chief executive of State Grid. Liu, a savvy operator with a talent for navigating party politics, almost immediately began to lobby hard for ultra-high-voltage projects, according to *Sinews of Power: The Politics of the State Grid Corporation of China*, by Xu Yi-Chong, a professor at Griffith University in Australia.

Lines capable of sending more energy over greater distances could stitch together China's fragmented grids, instantly delivering excess electricity from one province to another in need, Liu argued. Later, as the government came under growing pressure to clean up pollution and greenhouse-gas emissions, State Grid's rationale evolved: the power lines became a way to accommodate the growing amount of renewable energy generation.

From the start, critics asserted that State Grid was pushing ultra-high-voltage transmission primarily as a means of consolidating its dominant position, or that the new technology was an expensive and risky way of shoring up rickety energy infrastructure.

But Liu's arguments won out: early projects were approved and built, and party leaders soon prioritized ultra-high-voltage technology in China's influential five-year plans.

The company at first collaborated closely with foreign firms developing transmission technology, including Sweden's ABB and Germany's Siemens. But it quickly assimilated the expertise of its partners and began developing its own technology, including high-voltage transformers as well as lines that can function at very high altitudes and very low temperatures. State Grid has also developed software that can precisely control the voltage and frequency arriving at destination points throughout the network, enabling the system to react rapidly and automatically to shifting levels of supply and demand.

The company switched on its first million-volt alternating-current line in 2009 and the world's inaugural 800,000-volt direct-current line in 2010. State Grid, and by extension China, is now by far the world's biggest builder of these lines. By the end of 2017, 21 ultra-high-voltage lines had been completed in the country, with four more under construction, Liu said during a presentation at Harvard University in April.

Collectively, they'll stretch nearly 23,000 miles and be capable of delivering some 150 gigawatts of electricity—roughly the output of 150 nuclear reactors.

"The fact of the matter is, the Chinese are the only ones seriously building it at this point," says Christopher Clack, chief executive of Vibrant Clean Energy and a former researcher with the US National Oceanic and Atmospheric Administration.

GOING GLOBAL

In late February of 2016, Liu walked to the lectern at an energy conference in Houston and announced an audacious plan: using ultra-high-voltage technology to build an energy network that would circle the globe.

By interconnecting transmission infrastructure across oceans and continents, in much the way the internet links computers, the world could tap into vast stores of wind power at the North Pole and solar along the equator. This would clean up global electricity generation, cut energy costs, and even ease international tensions.

"Eventually, our world will turn into a peaceful and harmonious global village—a community of common destiny for all mankind with sufficient energy, blue skies, and green land," Liu said.

Of course, a completely global grid won't happen. It would cost more than $50

Collectively, they'll stretch nearly 23,000 miles and be capable of delivering some 150 gigawatts of electricity—roughly the output of 150 nuclear reactors.

Liu Zhenya initiated State Grid's ultra-high-voltage strategy and now oversees the company's efforts to promote international transmission lines.

trillion and require unprecedented—and unrealistic—levels of international trust and cooperation. Moreover, few nations are clamoring for these kinds of high-voltage lines even within their boundaries.

A handful of countries already exchange electricity through standard transmission lines, but efforts to share renewable resources across wide regions have largely gone nowhere. Among the notable failures is the Desertec Industrial Initiative, an effort backed by Siemens and Deutsche Bank a decade ago to power North African, Middle Eastern, and European electricity grids with solar power from the Sahara.

But State Grid's global grid plan is basically a sales pitch for its long-distance transmission lines, promoting them as an enabling technology for the clean-energy transition. If all the company ever achieves are the opening moves toward the vision of global interconnectivity, and it develops regional grids connecting a handful of nations, it could still make a lot of money.

Notably, at a conference in Beijing the month after Liu's speech, the company signed a deal with Korea Electric Power, Japan's Softbank, and Russian power company Rosseti to collaborate on the development of a Northeast Asian "supergrid" connecting those nations and Mongolia.

Kenichi Yuasa, a spokesperson for the Japanese conglomerate, said feasibility studies completed in 2016 and 2017 showed that grid connections among Mongolia, China, Korea, and Japan, as well as a route between Russia and Japan, are "technically and economically feasible." "We, as a commercial developer, are ready to execute the projects and would like to deliver tangible progress before [the] Tokyo Olympics in 2020," he said in an e-mail.

In a response to inquiries from MIT Technology Review, State Grid disputed that the broader global interconnection plan won't happen, or that its driving motivations are primarily financial and geopolitical.

"The great success of UHV technology application in China represents a major innovation of power transmission technology," the company said in a statement. "State Grid would like to share this kind of technological innovation with the rest of the world, addressing a possible solution to vital concerns for humankind, for example environmental pollution, climate change, and lack of access to electricity supply."

CLEANING UP OR *CLEANING UP*?

Though China has built far more ultra-high-voltage lines than any other country, its own grid is still something of a mess. The country is struggling to efficiently balance its power production and demand, and to distribute electricity where and when it is needed. One result is that it isn't making full use of its existing renewable-power plants. A recent MIT paper noted that China's rates of renewable curtailment—the term for when plants are throttled down because of inadequate demand—are the highest in the world and getting higher.

Part of the problem is that it's easier and more lucrative to use "predictable electrons" from sources like coal or nuclear, which provide a constant stream of electricity, than the variable generation from renewables, says Valerie Karplus, former director of the Tsinghua-MIT China Energy and Climate Project. Provincial politics and mandatory quotas for fossil-fuel plants also distort allocation decisions, she adds.

Fewer than half the ultra-high-voltage lines built or planned to date in China are intended to transmit electricity from renewable sources, according to a late-2017 report by Bloomberg New Energy Finance.

"Getting the most out of wind, solar, and other intermittent sources will require rethinking how to make grid operations more flexible and responsive," Karplus said in an e-mail.

Despite its purported green ambitions, State Grid itself has resisted the broader market reforms that would be necessary to lessen China's dependence on fossil-fuel plants. That casts doubt on the company's commitment to cutting greenhouse-gas emissions, and calls into question whether the long-distance lines will really help clean up power generation elsewhere.

Tellingly, State Grid's main target markets are poor countries where fossil-fuel plants dominate and Chinese companies are busy building hundreds of new coal plants. So there's little reason to expect that any ultra-high-voltage lines built there would primarily carry energy from renewable sources anytime soon.

"I haven't seen anything that would make me think this is part of a green-development initiative," says Jonas Nahm, who studies China's energy policy at the Johns Hopkins School of Advanced International Studies. "I think State Grid just wants to sell these things anywhere and dominate with its own standards over those developed by Siemens and other companies."

He believes State Grid's broader ambitions are tied to the Belt and Road Initiative, through which China's state banks are plowing trillions into infrastructure projects across Asia and Africa in an effort to sell Chinese goods and strengthen the country's geopolitical influence. Building, owning, or operating another nation's critical infrastructure—be it seaports or transmission lines—offers a particularly effective route to exercise soft and sometimes not-so-soft power. "This is really a battle over the developing world," Nahm says.

James Temple is MIT Technology Review's senior editor for energy.

The rockets'

A Long March 2D rocket carrying a Chinese reconnaissance satellite blasts off from the Jiuquan Satellite Launch Center in 2008.

red glare

Will a cohort of new startups vault China to a lead in space?

by Joan Johnson-Freese

Late one afternoon last October, from a remote and desolate launchpad in the Gobi desert, the Future soared into space.

The Future, a small satellite built for a China Central Television science show, was scarcely more capable than the very first Chinese satellite, launched from the same spot, the Jiuquan launch center, in 1970. And yet October's launch was historic: it was to be the first privately developed Chinese rocket to reach orbit.

Zhuque-1, the rocket carrying the Future to orbit, has three stages. The first stage fired smoothly. So did its second. A few minutes later, the third stage malfunctioned. The Future was lost.

Spaceflight is hard, and failure of new rockets common. SpaceX's first three launches failed: as its founder and head Elon Musk tells it, the fourth, successful launch came just before money ran out. SpaceX has changed the face of the US aerospace industry. After decades of domination by old-line companies, SpaceX is the most prominent of a new generation of firms that, by dramatically lowering launch costs, seek to revolutionize both human space travel and the satellite launch market.

Now that revolution is coming to China as well. Landspace, the firm that built the Zhuque-1, is not the only firm trying. At the time of this writing, in December 2018, another company, OneSpace, was also planning an orbital launch for later in the year while a third, iSpace, has ambitions for 2019.

Regardless of which company wins the race, two things are clear. Privately funded space startups are changing China's space industry. And even without their help, China is poised to become a space power on par with the United States.

As American and Russian space programs struggle with uncertain budgets, China is expanding its efforts on every front: communications and reconnaissance satellites; a navigation and positioning constellation to rival America's GPS; a human spaceflight program; and ambitious space-science and robotic exploration projects. All of these are enabled by a menagerie of new rockets with advanced capabilities.

Depending on how the weather at China's four spaceports compares with that in Florida and California, 2018 may be the first year in which more rockets reach Earth orbit from China than from any other country. As of early December, China was on pace for nearly 40 successful launches.

A planned December launch from the Xichang Satellite Launch Center in Sichuan (nearly a thousand miles southeast of the Jiuquan launch center) will send a robotic rover called Chang'e 4 to land on the far side of the moon. If it succeeds, it will be the first spacecraft to do so: China's space program is coming of age.

BY THE DAWN'S EARLY LIGHT

In 2014, the Chinese government decided to allow private investment in space-related industry. Landspace began with a few dozen people. It now has over 200 employees at a manufacturing base in Huzhou in eastern China and at assembly and testing facilities in X'ian, a central Chinese city. The company plans to work incrementally, beginning with nanosatellites—devices weighing between 1 and 10 kilograms (2 to 22 pounds)—then moving to larger cargoes and, eventually, into human spaceflight.

Landspace already has a contract with a Danish firm to launch a series of nanosize Earth observation and communications satellites into orbit around the equator. Having foreign contracts on the books is important not only because it brings in money, but also as a marker of confidence that China's space companies are for real.

In September 2018, iSpace launched three nanosatellites on a brief suborbital flight, becoming the first Chinese space startup to successfully get beyond Earth's

atmosphere. Another company, LinkSpace, plans to launch a vertical takeoff, vertical landing rocket in 2020. Landspace, OneSpace, iSpace, LinkSpace, and ExPace (which fashions itself as a startup though it's a subsidiary of a state-owned enterprise) are the leaders of a bevy of lesser-known Chinese launch startups.

These launch companies are operating hand in hand with a number of new, privately funded Chinese companies that are focused on doing things *in* space, rather than on getting there. Spacety and Commsat, among others, are planning large constellations of small imagery and communication satellites.

Such constellations—whether Chinese or American—are transforming aspects of the way space is used. By making low-resolution satellite imagery much cheaper to gather (among other novel applications for small satellites), they are catalyzing an era of more nimble commercial, scientific, and military experimentation.

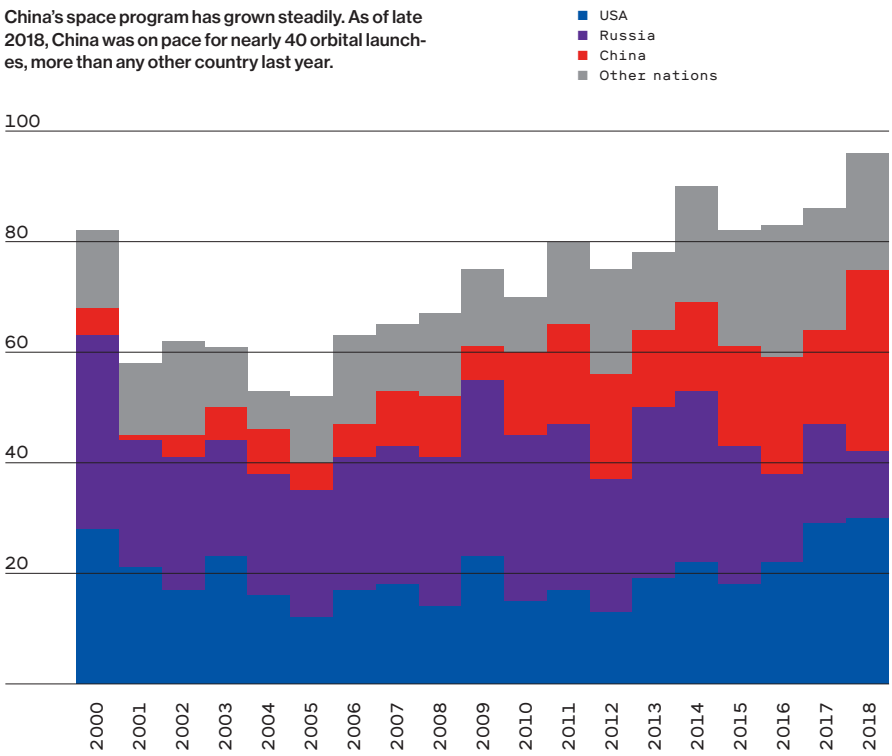
However, human space exploration requires heavy-lift rockets in order to launch space station modules, or to send people back to the moon or on to Mars. You also need heavy-lift rockets to put large communications satellites into geostationary orbit, where they can linger over a particular patch of ground. (Geostationary orbit is about 100 times farther away than low-Earth orbit, and it takes a lot more energy to get there.) And you need them for sample-return missions that aim to bring chunks of the moon or Mars back to Earth.

Unlike SpaceX, none of the new Chinese space startups are developing such rockets. But China is.

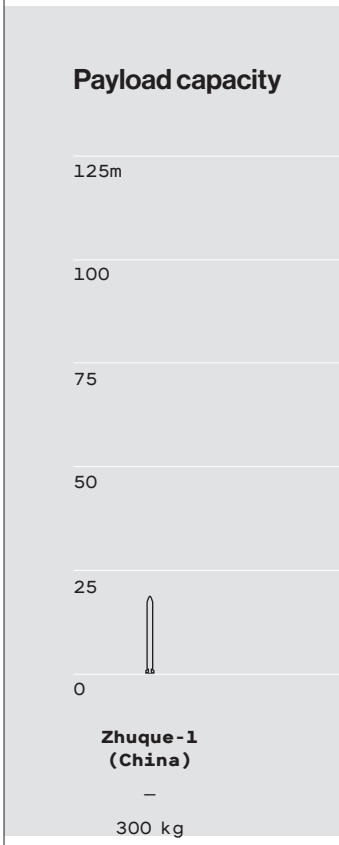
China's established aerospace industry is an alphabet soup of state-owned enterprises that are the legacies of Russian-style numbered institutions and bureaus from Mao's days. The largest, Chinese Aerospace Science and Technology Corporation (CASC), is about as big as

Orbital launches by nation 2000–2018 (as of November)

China's space program has grown steadily. As of late 2018, China was on pace for nearly 40 orbital launches, more than any other country last year.

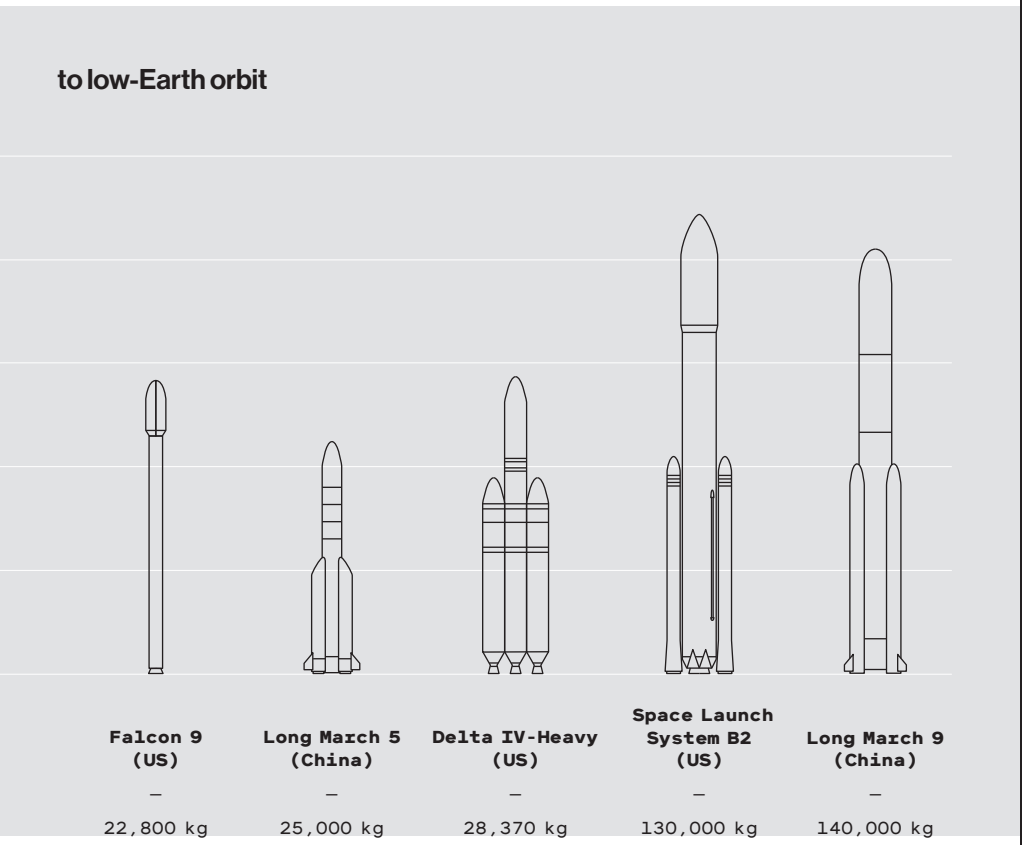


Space technology will provoke tensions regardless of who holds power. Missiles and satellites are launched the same way.



China is also developing a space telescope that will have the same resolution as the Hubble—but a field of view 300 times larger.

PREVIOUS SPREAD: XU HAIHAN/GETTY IMAGES; SOURCE: PROJECT SPACE TRACK/US AIR FORCE



Boeing—it employs over 140,000 workers. A subsidiary called the China Academy of Launch Vehicle Technology (CALT) built the Long March 5, China's first heavy-lift rocket. CALT is also working on a super-heavy-lift rocket that, when completed in a few years, might become the most powerful ever built.

The Long March 5's first flight, in November 2016, was a success. But rocket science is, well, rocket science. More powerful rockets aren't just a matter of scaling things up: the complexity grows quickly. That first flight had been delayed for years as engineers worked out kinks in the cryogenic engines. Six minutes into the second flight, in July 2017, a turbo pump failed and the rocket crashed into the sea.

A number of China's ambitious plans are on hold until the Long March 5 starts flying again. If all goes according to plan, its next launch in January 2019 will carry a large, high-capacity communications satellite to geostationary orbit. The following launch, planned for later in 2019, will send Chang'e 5 to the moon—and back. If it succeeds, it will be the first such sample-return mission since the Soviet Union's Luna 24 brought 170 grams of lunar soil back to Earth in 1976.

China's next step in human spaceflight will be a large, permanently crewed space station. The launch of the station's core module by a Long March 5 is planned for 2020, the first step toward a complete station by 2022. Even when complete, China's space station will be only about a fifth the size of the International Space Station (ISS). But it will be entirely China's, while the ISS's future as a US-Russian collaboration (with some assistance from other countries) is in doubt.

China is also developing a space telescope that will have the same resolution as the Hubble—with a field of view 300 times larger. The telescope will be placed in orbit close to the space station, so that Chinese astronauts can quickly service the instrument should problems arise. CALT has learned from NASA's mistakes—it took over three years for NASA to fix Hubble's flawed mirror.

Assuming CALT works out the kinks, the Long March 5 will transform China's space capabilities. The successor CALT is developing, the Long March 9, whose first flight is penciled in for 2028, will be able to heave 140 metric tons into orbit, more than five times as much as the Long March 5. In capacity it will compare to the Saturn V—still the most powerful rocket ever built—and far exceed the most ambitious version of NASA's Space Launch System (SLS), which is also planned for 2028 (at the earliest). The Long March 9 would be capable of landing a man on the moon, and of launching a Mars sample-return mission.

The SLS and Long March 9 could both be delayed by technical setbacks. The difference is that where NASA's plans have shifted with each new administration and struggled to find support in Congress, CALT has had a steady mandate from the Chinese government.

The relationship between the US and China has deteriorated under the Trump administration. But the dual-use nature of space technology will provoke international tensions regardless of who holds power in either country. Missiles and peaceful satellites are launched the same way. Environmental monitoring satellites and military reconnaissance satellites are similar; communications satellites can transmit top-secret orders or provide Wi-Fi to airline passengers. Maneuverable satellites for refueling and repairing other satellites can also be used as weapons against an adversary's orbital platforms.

The US has spent considerable time trying to figure out how to stymie Chinese space plans. It blackballed China from the ISS; a widely criticized 2011 law prohibits bilateral contact between NASA and Chinese scientists. Such efforts are counterproductive. They isolate the US without acting as a meaningful check on Chinese ambitions. To stay ahead, the US will have to get its own house in order, rather than trying to hobble the competition.

Joan Johnson-Freese is a professor of national security affairs at the Naval War College.

ILLUSTRATIONS BY KYLE THOMAS HEMINGWAY

THE FATHER

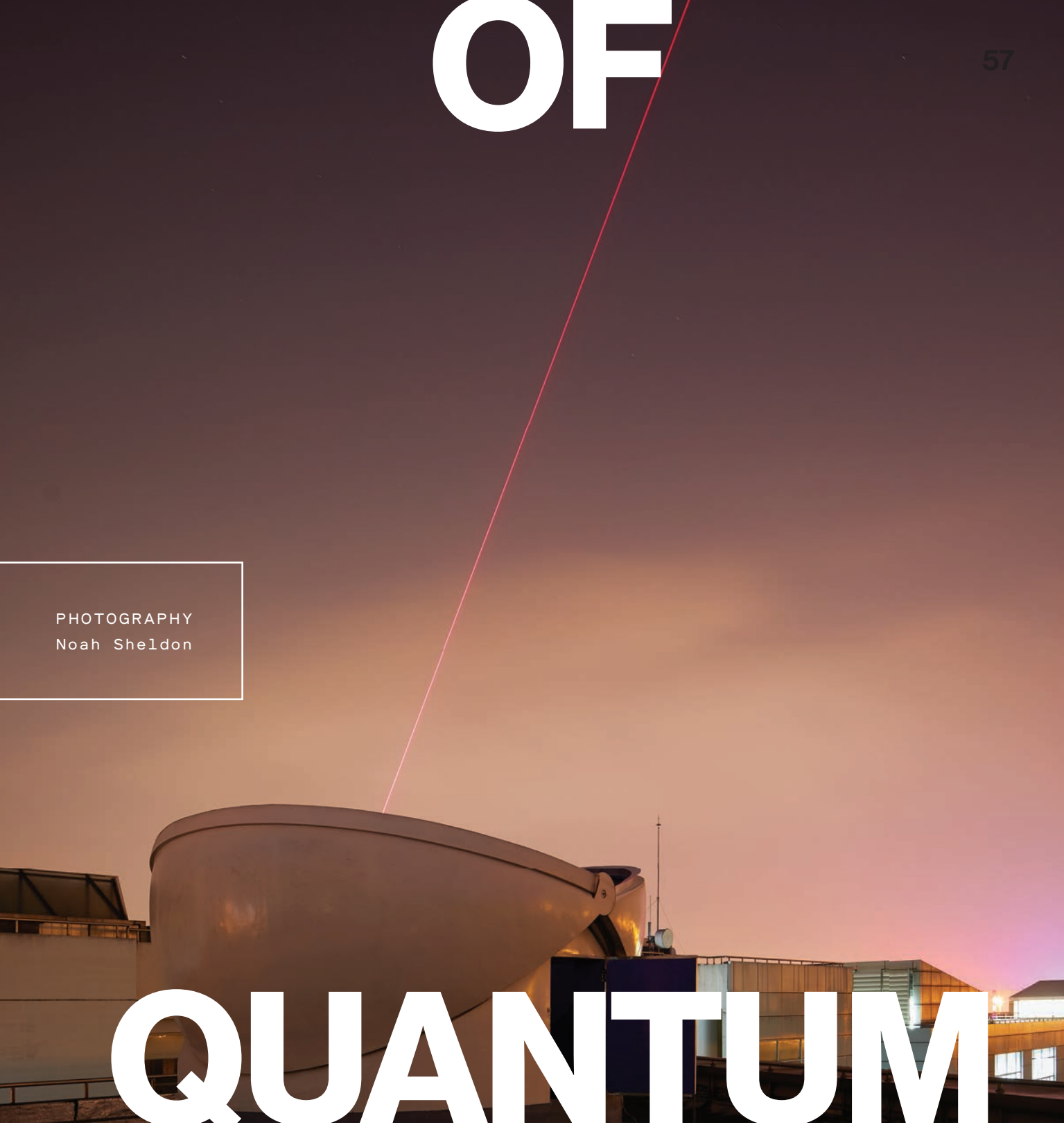
B Y
Martin Giles

Jian-Wei Pan is turning China into a quantum superpower, leading the way in technologies that could transform entire industries and change the way wars are fought.

On September 29, 2017, a Chinese satellite known as Micius made possible an unhackable videoconference between Vienna and Beijing, two cities half a world apart. As it whisked across the night sky at 18,000 miles (29,000 kilometers) per hour, the satellite beamed down a small data packet to a ground station in Xinglong, a couple of hours' drive to the northeast of Beijing. Less than an hour later, the satellite passed over Austria and dispatched another data packet to a station near the city of Graz.

The packets were encryption keys for securing data

OF QUANTUM



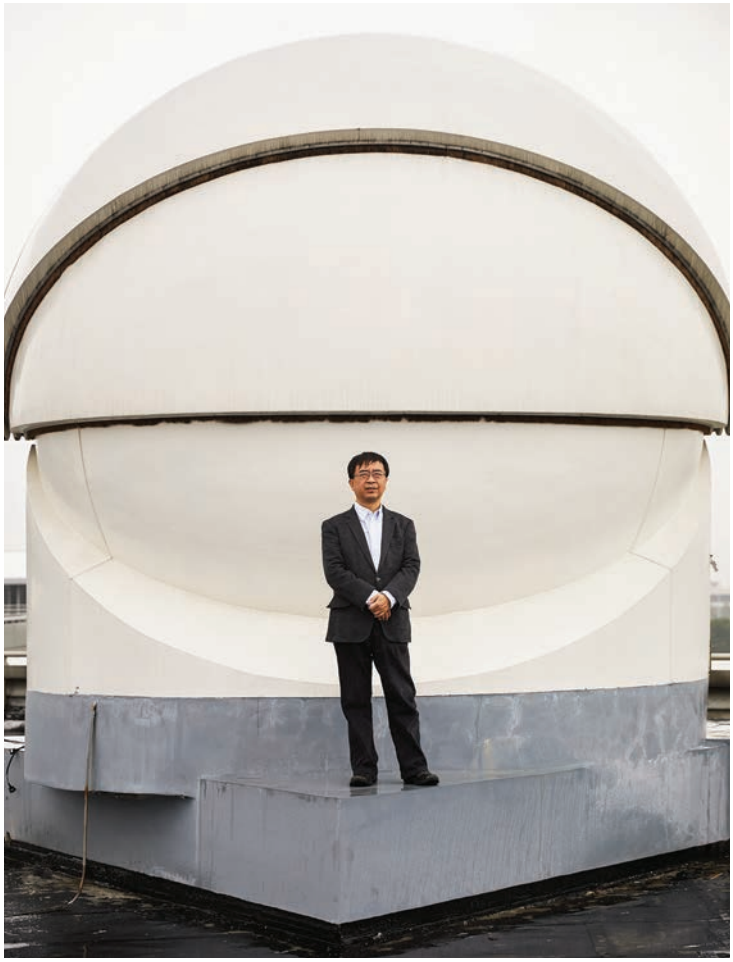
PHOTOGRAPHY
Noah Sheldon

transmissions. What made this event so special was that the keys distributed by the satellite were encoded in photons in a delicate quantum state. Any attempt to intercept them would have collapsed that state, destroying the information and signaling the presence of a hacker. This means they were far more secure than keys sent as classical bits—a stream of electrical or optical pulses representing *1*s and *0*s that can be read and copied.

The video encryption was conventional, not quantum, but because the quantum keys were required to decrypt it, its security was guaranteed. This made it the world's very first quantum-encrypted intercontinental video link.

The man behind this achievement is Jian-Wei Pan. A professor at the University of Science and Technology of China (USTC), sometimes known as "China's Caltech" (see our story about it on page 70), 48-year-old Pan has produced a series of breakthroughs that have propelled him to scientific stardom in the country. His work has won plaudits from President Xi Jinping, and he's often referred to in local media as "the father of quantum."

Quantum communications and computing are still nascent,



Jian-Wei Pan, standing in front of a receiver used in the transmission of ultra-secure signals from the Micius satellite, has helped lead China's quantum efforts. The picture of the receiver on the previous page shows a spotting laser used to help the satellite connect to the ground station.

but they are among the technological "megaprojects" on which China's government wants breakthroughs by 2030. It sees an opportunity to lead the dawning quantum era in much the same way that the US dominated the advent of computing and the information revolution that it sparked.

Pan, who in 2011 became the youngest-ever member of the Chinese Academy of Sciences, is central to this effort.

In an interview with MIT Technology Review, Pan talked about the importance of international collaboration, but he also made clear that China sees a unique window for it to shape the next meta-shift in the technology landscape. "We were only the follower and the learner at the birth of modern information science," he said. "Now we have a chance … to be a leader."

Pan's ambitions include a plan to create a globe-spanning constellation of satellites that constitute a super-secure quantum internet. Also on his checklist: helping China catch up with—and perhaps overtake—the US in building powerful quantum computers. The fundamental units of computation in these machines are qubits, which—unlike bits—can occupy a quantum state of *1* and *0* simultaneously. By linking qubits through an almost mystical phenomenon known as entanglement, quantum computers can generate exponential increases in processing power.

In the future, the machines could be used to discover new materials and drugs by running simulations of chemical reactions that are too much work for classical computers. They could also turbocharge artificial intelligence. Secure networks using quantum key distribution (QKD) could transmit sensitive data for things like financial transactions and provide utmost secrecy for military operations and communications. Researchers are also working on quantum sensors that would let submarines navigate without relying on satellite signals, and quantum radar that may be able to spot "stealth" aircraft.

JOINT EFFORTS

Despite the intense US-China competition in quantum technologies, the video call made possible by the Micius satellite—named for an ancient Chinese scientist and philosopher—is very much a result of international cooperation.

It came out of a collaboration between a team led by Pan and another led by Anton Zeilinger, a quantum physicist at the University of Austria. Zeilinger was Pan's doctoral supervisor in the 1990s, and he saw potential in the young Chinese student. "When he came here, he was one hundred percent focused on theoretical physics," recalls Zeilinger. "But I realized he could do more, so I suggested he switch to experiments, and he did that very successfully."

So successfully, in fact, that Zeilinger was only too happy when his former student proposed a collaboration on intercontinental QKD in 2011. Pan's team had already conducted experiments over a number of years to prove a space-based system could work, and it eventually got the Chinese government's green light to build a dedicated satellite, which was launched in 2016.

Making QKD work on the ground is hard enough. Doing it from a satellite meant solving a host of extra problems, from aligning the satellite's transmissions precisely with the ground stations to minimizing the number of photons lost in the atmosphere. Observers were impressed, says Hoi-Kwong Lo, a physics professor at the University of Toronto. He adds, "There's a huge amount of resources being devoted to quantum in China, which means they can do things other countries can't."

China's other achievements include building the world's longest terrestrial QKD network. The 2,032-kilometer (1,263-mile) ground link between Beijing and Shanghai was also masterminded by Pan and sends quantum-encrypted keys between way stations, offering an ultra-secure network for

transmitting financial and other sensitive data. Some Chinese cities are also building municipal networks.

Gauging exactly how much China is investing in these and other quantum projects is hard because funding for government programs is opaque. But Pan says the money devoted to an upcoming national quantum plan for China will be "at least the same order of magnitude" as Europe's recently launched Quantum Technologies Flagship project, a 10-year, €1 billion ($1.1 billion) initiative.

While money matters, there's more to China's success than the bankrolling of satellites and other projects.

To help develop future quantum researchers, the country is building a $1 billion National Laboratory for Quantum Information Sciences in Hefei that will open in 2020; it will bring together experts from a range of disciplines such as physics, electrical engineering, and materials science. Some of the money will be for a new USTC campus on the same site to train quantum researchers. "We are working hard to develop the workforce of the future in quantum technology," says Pan.

He's already created a center for quantum information and quantum physics at USTC. In June 2018 a team at the center announced it had set a world record for entangling qubits, linking 18 together. Advances like this will bring us closer to the point at which a quantum machine will finally be able to outstrip even the most powerful conventional supercomputer for certain tasks.

There are also ambitious plans to scale up efforts in space. Pan says that over the next four to five years, China will launch four more low-orbit quantum satellites, and a high-orbit geostationary one will follow shortly thereafter. The long-term vision is to create a continent-spanning, quantum-secured internet that could eclipse today's version. Looking much further ahead, the technology could one day be used to secure everything from smartphones to laptops.

> Pan foresees a day when data centers on different continents will be connected via the quantum satellites he's planning.

The country also benefits from a decades-long strategy of sending young researchers abroad to learn from experts like Zeilinger and then enticing them home to continue their work.

China is producing plenty of high-quality quantum science papers, and the number of Chinese patents being registered in areas like quantum communications and quantum cryptography has also soared, far surpassing those being registered in the US and elsewhere.

LEADER AND LAGGARD

So is China really set to dominate the emerging quantum era? And what will it do with that dominance if so?

The answer to the first of those questions is nuanced. While Micius and the ground-based QKD networks give China the edge—for now—in secure quantum communications, it still trails the US in quantum computing. However, as Pan's team's success with entangling qubits shows, it's making swift progress. Big Chinese tech companies like Alibaba and Baidu are investing heavily in quantum computing, too. Alibaba has launched a cloud computing service that lets people experiment on quantum processors, mirroring similar efforts by US companies such as IBM and Rigetti.

Isaac Chuang, an MIT professor and pioneer of quantum computing, notes that one of the reasons China has done so well in quantum science is the close coordination between its government research groups, the Chinese Academy of Sciences, and the country's universities. Europe now has its own quantum master plan to prompt such collaborations, but the US has been slow to produce a comprehensive strategy for developing the technologies and building a future quantum workforce.

Whatever happens elsewhere, China will press forward. Pan emphasizes commercial opportunities. Businesses are already using the Beijing-Shanghai network to ship information securely. And he foresees a day when data centers on different continents will be connected via the constellation of quantum satellites he's planning.

Those satellites, of course, could also be used for military purposes. Elsa Kania at the Center for a New American Security, a Washington, DC, think tank, says various parts of China's armed forces are funding research into quantum communications, sensors, and radar. Big companies like China Shipbuilding Industry Corporation, one of the country's largest builders of warships and submarines, are working with universities on quantum projects. If China thinks the technology could give it a military edge, it might pull back on international collaborations and keep innovations to itself.

A more optimistic view sees China remaining open to the kinds of interchanges that have helped turn it into a quantum superpower, and doing its utmost to profit from a new, quantum-inspired data economy. The notion that China could seize the lead here seems to inspire its top officials: Xi Jinping has even talked publicly of quantum science opening up "a new industrial revolution."

Whichever scenario ultimately plays out, China will be counting heavily on the father of quantum to steer it to success.

Martin Giles is MIT Technology Review's San Francisco bureau chief.

THE ART OF TECH

3 OF 3

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A computer scientist by background, Xu Wenkai, who also goes by aaajiao, recently moved from Shanghai to Berlin. He admits to a pessimistic view of how technologies shaped by nationalism in turn affect culture. However, his criticisms are not aimed at China alone. Despite the differences between the ways China and the West absorb new technology, Xu says, we're all headed the same way: "[China and the West] are at different points on the same time line, but it's hard to find a reference point to compare these differences. They are each other's past, as well as each other's future." The creative, complex responses to censorship seen in work by Xu and Miao Ying give an early idea of the strange form this future might assume. —*Josh Feola*

Censorship

artist: Miao Ying _____ project: *Problematic GIFs*

Miao Ying's *Problematic GIFs* comments on tools of censorship as they're applied to the Chinese social messaging platform WeChat. The error screen that displays when an image fails to load is ironically presented front and center as a non-portrait, obscured by censorship and surrounded by freeze-frames of GIFs popularly used on WeChat.

artist: aaajiao _____ project: *GFWlist*

In this installation, aaajiao hints at what might be the physical length of China's "Great Firewall"—a sophisticated infrastructure for blocking websites and search terms—by printing out the URLs it restricts. The monotonous, serial repetition echoes the manual labor required to constantly monitor and block sensitive material, the never-ending work of the government's internet watchdogs.

COURTESY OF MADEIN GALLERY (MIAO YING); COURTESY OF THE ARTIST

The man who crossed the ger

mline

Three years ago an unknown Chinese scientist edited the DNA of human embryos. It was a step on an inexorable path to designer babies.

By Antonio Regalado

It could have been anyone. It was so easy. But it was him. Junjiu Huang.

In 2015, Huang, a stem-cell researcher at Sun Yat-Sen University in Guangzhou, first reported using the gene-editing tool CRISPR on human embryos. His paper was rejected by top Western journals on the grounds that it didn't follow ethics rules and presented scant science, but that April it found its way into print in an obscure English-language publication in Beijing.

The result was, in Chinese, *xuān rán dà bō* (轩然大波), or "towering waves"—a sensational controversy.

Huang had only carried out a lab experiment, in which he'd tried to fix a gene error that causes a blood disease. His test subjects were abnormal IVF embryos, about the size of the period at the end of this sentence, and they were soon destroyed. No attempt was made to create a child.

Still, Huang had broken a taboo: altering the DNA of so-called germline cells, those that affect heredity.

The implication was clear. Genetically edited people could one day be born. And those changes would be passed on to future generations.

The reaction to Huang's work was instant, visceral, and global. Humankind could drive its own evolution, but the person holding the wheel was a youthful-looking biologist from southern China whom no one had ever heard of. His scientific effort was called "totally premature" and a "dreaded" experiment. The dean of Harvard Medical School ascribed to Huang potentially "deranged motivations."

I wrote about Huang's research in 2015, so it was with a sense of déjà vu that I watched the international reaction this November when He Jiankui, a scientist at the Southern University of Science and Technology in Shenzhen, announced he'd changed the DNA of human embryos to make them HIV-resistant and implanted them into women—one of whom, He claimed, gave birth to twin girls. Once again, an ambitious Chinese scientist had crossed into unknown territory to score a controversial first. Once again, his papers were rejected and attacked by furious Western scientists.

These events have made it apparent that the scientific community is deeply uncertain and conflicted about how to roll out a technology that will affect humanity's shared gene pool. He's shocking baby announcement came just before a major international summit in Hong Kong whose purpose had been to discuss gene-editing technology and its implications for reproduction—that is, to determine whether there should be CRISPR babies at all. Despite the wave of anger at He's news, the summit leaders did not conclude that humankind isn't responsible enough to engineer its own heredity or should enact a moratorium while we learn a bit more. Rather, it ended with the clearest call yet by science leaders to move the technology toward medical use in IVF clinics.

The dream is that future generations will benefit from longer and healthier lives because their bodies possess genetic vaccines against heart disease, Alzheimer's, and more. The nightmare, though, may be pretty close to what He was allowed to present on stage in Hong Kong: children whose genomes were clumsily and needlessly mutated as part of an international science race.

It could still be that China's government cracks down on the gene-editing efforts: at the time of writing, He was under investigation by everyone from the local health board to China's ministry of science and technology, and he had vanished from view. In the US, starting pregnancies with gene-edited embryos was blocked by Congress in 2015. But American researchers have been prowling labs in China, looking to set up shop there and push CRISPR babies forward in ways they can't at home.

Once gene editing was developed, the pace of technological exploration made it inevitable that someone would create a birth, and someone will again. Even if the technology doesn't move forward in China, it will just happen somewhere else.

The dream is that future generations will benefit from longer and healthier lives. The nightmare, though, is children whose genomes are clumsily and needlessly mutated as part of an international science race.

THE SPARK

I had traveled to China in October, a full month before the announcement of the CRISPR babies, to understand the country's intentions for embryo engineering, an area in which its scientists had taken a notable lead: of the 10 papers I could locate describing lab-edited embryos, eight were from China, and one each from the US and the UK. Whatever was happening, China would be the place to learn about it. If there was a secret project to make a baby, perhaps I could unearth it. I began with Huang, who had dropped off the media radar entirely in 2015.

Huang told me that our interview, in a tea house in Guangzhou, was the first he'd given since his paper was published three and a half years ago. Even now, he did not want to recall the international censure his first embryo-editing report had generated, nor the towering pile of inquiries that flowed into his in-box. "I don't remember," he said.

Huang was ready to speak because passions had cooled and embryo editing had become an accepted, if limited, line of research. (When US scientists edited embryos in 2017, it was heralded as a "breakthrough.") Many had begun to see the procedure as a potential new way to prune risks of genetic disease from tomorrow's children. Huang slowly relaxed his guard. He told me he was married and played volleyball. The means to edit embryos and alter heredity? "A necessity of history," he said.

Yet Huang appeared to have no inkling of the news He would soon reveal. When I asked him what advice he would have for anyone in a rush to start a clinical trial in an IVF clinic, he said he thought it was unlikely

anyone was trying. "We are far from the proper timing for this," he said.

Huang's life story would be familiar to many Chinese scientists—"just normal," he said. He grew up on a farm, but his family moved to a town so his parents could work in a factory building boat parts and send him to school, where he was singled out for his high grades.

Even as a boy, he says, he found the embryo a source of fascination. He mated purple, white, and green corn to make hybrids, and during the 1990s he followed popular reports of a Chinese effort to clone a panda. "I thought the embryo was a very mysterious type of cell," he says. "It has all the information needed to form something, but how does the process work?"

So Huang noticed when, in 2012, US, European, and South Korean scientists developed a versatile new way to alter the DNA information inside living cells. Called by its acronym, CRISPR allows scientists to easily cut open the double helix at any location so they can add or remove genetic instructions. A few hundred dollars' worth of supplies and chemicals is all that's needed.

By May 2013, a team at MIT, led by Rudolf Jaenisch, had injected CRISPR into mouse embryos, leading to the birth of the first CRISPR-modified mammals. But China, with its loose rules on animal research and its ambitions to become a worldwide leader in the technology, rapidly claimed the rest of the animal zoo. "We lost the mouse. But we won the sheep, the goat, and the monkey," says Huang Xingxu (no relation), a professor of biology at Shanghai Tech University.

The birth of two edited monkeys in Yunnan province, announced in January 2014, led some observers to realize that edited humans might be next. But who would take such a step? What kind of social understanding or global agreement might be needed? There was none.

Huang says he had "no idea what the reaction would be" to his research.

XUEXUN ZHOU

Junjiu Huang says he first introduced CRISPR into human embryos just three months after the monkey report. It was, as some feared, very simple to do. "We spent about half a year to finish the project, because it's not a very complex experiment," he says.

Huang was well positioned to do it. Guangzhou has large, well-established IVF clinics interested in research. And Huang also perceived the need for a new form of treatment. About 10% of the population in the growing city of 13 million carries a genetic error that creates a risk for beta thalassemia, a blood disease. What if CRISPR could be used to replace the broken gene with a working copy in embryos? That, he imagined, would be a "new technique" to eradicate the disease in newborn children. In his tests, Huang worked with abnormal embryos rejected by the IVF lab.

"I was doing basic research … to test the feasibility," he says. He admits he had "no idea what the reaction would be."

"IRRESPONSIBLE" FOR NOW

It wouldn't take long to find out. Huang's effort to install a normal beta thalassemia gene in embryos did work sometimes, but there were serious problems. CRISPR is error prone and can make unwanted edits, called "off targets." It meant the chance of introducing new and potentially harmful mutations. Also, the process wasn't efficient. Often the embryo ended up with a mixture of corrected and uncorrected cells, a so-called mosaic—a problem that was to end up afflicting most of He's embryos as well.

To many scientists, the risk of unwanted and undetected errors is what makes it so unwise to create a CRISPR baby. "It's clearly not ready," says Zheng-Yi Chen, a Harvard University scientist who works with CRISPR in pigs in China. "You don't know the consequences to develop a whole human being. Any subtle difference could be magnified by a billion- or trillion-fold. It could change the landscape."

Gestation period

Since the invention of the gene-editing tool CRISPR, its use to modify human beings has proved inexorable.

2012

US and European scientists develop powerful and easily programmed molecules for cutting DNA. The gene-editing tool is named CRISPR-Cas9.

2013

The first gene-edited monkeys are born in southern China. Scientists deleted two genes from their bodies.

2014

Chinese researchers begin altering human embryos with CRISPR. They aim to correct the mutation causing the blood disorder beta thalassemia.

Huang's lab results alarmed top Western biologists who reviewed them starting in late 2014. They claimed the work was sloppy and made sure his submission was rejected by both Science and Nature, the world's premier science journals. But in truth, the experts were shocked by how advanced the Chinese work was. Before Huang could publish his report elsewhere, American biotech executives who had seen his text called for an immediate moratorium on all embryo editing. Their editorial, published by Nature, was titled "Don't edit the human germline."

It would be the first, and last, organized call from gene-editing experts to shut down the lab research. Days later, a broader group of specialists, writing in Science and including Jennifer Doudna, a co-discoverer of CRISPR, took the position that lab studies should be encouraged but called for an urgent international meeting to "explore responsible uses of this technology." That meeting, eventually held at the National Academy of Sciences in Washington, DC, in December 2015, drew top biologists and ethicists from around the world, including China.

Biologists have struggled to understand their own power and to contain the risk that governments could step in with regulatory restrictions on CRISPR. Seeing how quickly the technology was moving, David Baltimore, the former president of Caltech, speaking for the conference organizers, hit the pause button: he stated that making a baby would be "irresponsible" for now. Such an undertaking needed to wait until the technology was better studied and until there was a "broad societal consensus" about why we'd want to change the gene pool at all.

That summit statement after the meeting in Washington was agreed to by the scientific academies of the US, the United Kingdom, and China—the last of these an arm of the central government. Huang, the junior researcher who started it all, wasn't at the historic forum. "I was not invited," he says.

WHEN "NO" MEANS "MAYBE"

A year later, in February 2017, the US National Academy of Sciences published a detailed set of recommendations written by a cadre of mostly American senior scientists. It found that no country was yet in a position to safely create a human whose genes were altered with CRISPR. But the technology was not in itself impermissible, the scientists said. So long as such a project was aimed at preventing serious disease, was preceded by safety studies, and met other—somewhat undefined—conditions, it might be acceptable to try for a live birth.

In Shenzhen, He Jiankui was listening. A biophysicist and expert in DNA sequencing, he had studied at Rice and Stanford but had returned to China. He had a professorship, funding, and, it appears, the ambition of being the first in the world to produce a child genetically engineered with CRISPR. That March, according to documents, he came to an ethics committee at a South China hospital with a proposal for a clinical trial of a

MONKEYS: CELL, NIU ET AL. / EMBRYO: RWJMS IVF PROGRAM | WIKIMEDIA COMMONS

2015

Science leaders from China, the UK, and the US warn it would be "irresponsible" to create a child from edited embryos.

The US Congress forbids the Food and Drug Administration to allow the creation of genetically modified children.

2016

US intelligence agencies classify CRISPR as a potential weapon of mass destruction.

2017

The US National Academy of Sciences says it is permissible to genetically engineer humans, but only under extraordinary conditions.

2018

A researcher in China announces the birth of twin girls whose genomes were altered with CRISPR to make them resist HIV.

treatment intended to make children immune to HIV. He believed he could win the Nobel Prize. In those documents, He cited the US academy's report, telling others the Americans had "approved" the idea of germline editing—which, in some sense, they had.

In Shenzhen, He quickly began assembling the data that would let him meet the academy's standard—or something resembling it. He focused on two genes whose deletion from a person's genome can have a health benefit. One was CCR5, without which people can't usually get HIV. Deleting the other, PCSK9, leads to extraordinarily low levels of "bad" cholesterol and a much reduced chance of heart disease.

The ideas were ambitious—closer to an enhancement than a cure, since they'd prevent diseases in the future rather than correcting a DNA defect in the embryo. But they also met one of the American report's criteria—that CRISPR not be used to modify children if there were "reasonable" alternatives.

In most cases where parents carry a risk gene for an inherited disease, like cystic fibrosis, they will pass it on to only half their children—so the genetic error can be weeded out during IVF procedures by testing embryos and picking those that didn't inherit the faulty gene. Many scientists believe gene-editing embryos will never be necessary, for that reason. Only CRISPR, though, can endow a child with a trait—such as HIV immunity—that the parents didn't have. That's why He considered his approach to be fair game.

He's students began working on what turned into tests on more than 300 human embryos, plus countless mouse and monkey cells. The work was enabled by the Western CRISPR industry that had grown up to distribute the technology's components and, often, collect profits. For instance, in 2016 He had e-mailed the Broad Institute, in Cambridge, Massachusetts, seeking a license to its important CRISPR patent and rights to use the gene-editing tool in human beings. Broad declined, since it had already sold rights for human therapeutics to its own spinout company, Editas Medicine. Broad did, however, sell He a license to market CRISPR's key ingredients. (An official with Broad noted that all its legal agreements prohibit "any human germline modification" and that making babies is "a clear and flagrant violation.")

The He team also reached out to the scientific community on issues of science and ethics. Kiran Musunuru, a gene-editing scientist at the Perelman School of Medicine in Pennsylvania, recalls getting peppered with questions from a graduate student in He's lab: "Do you think these are reasonable and feasible?" wondered Feifei Cheng about some mouse experiments. The Chinese scientists didn't exactly hide their purpose, either. In one e-mail, Cheng said, "I think our research will illustrate whether ... genome editing in embryos, not in adult, is efficient and safe for the first time."

The focus on safety was the giveaway clue. Safe or not safe doesn't matter for a research embryo; they are all

destroyed after a few days of growth in a laboratory. Safety would only matter if you intended to create a pregnancy.

He Jiankui even took part in meetings and ethics symposia meant to determine whether babies should be made. "He spoke, but he didn't seem to listen," says Stuart Newman, a biologist at New York Medical College, who attended a January 2017 workshop at Berkeley organized by Doudna, where He was among those present. Doudna had always worried about how CRISPR could be misused and told a gathering of journalists that August that the sudden announcement of a CRISPR baby could be a "worst-case scenario." Now, He was headed back to China to do exactly that.

He was not dissuaded even by his own data. After he gene-zapped test embryos, his detailed DNA-sequencing studies of the outcome convinced him that the problem of unwanted, off-target edits was minimal and he would be able to see any that did occur. But he was not so easily able to control mosaicism—a result of the fact that CRISPR didn't always edit every cell in the embryo, or ended up editing cells in different ways. His data on test embryos found that the majority were mosaics, according to a 2017 presentation.

He: CRISPR babies are here.

ASSOCIATED PRESS

GENE SUPERPOWER

Chinese scientists are working in an atmosphere of loose regulations and great ambitions. China's government wants to lead the world in biotechnology. At an institute in Shanghai, I heard a speech by Zhou Qi, a prominent stem-cell scientist who was among a group that met last March in Beijing to map out a new government strategy for achieving that goal. "China," he said in the speech, "will put biotechnology as a very high, very important priority."

To achieve that, China has paid special attention to both gene editing and stem-cell research—the corner of biology dealing with the Promethean capacity of certain cells (including the fertilized egg) to form hearts, lungs, and any other body part. In October, Zhou led a team that—through a complex series of steps involving stem cells, gene editing, and cloning—had shown that two male mice could have offspring together. And I heard him tick off a list of unpublished results that sounded scientifically important and, I thought, were also all likely to cause sensational headlines.

In the Chinese-language literature, I found scattered boasting and calls to move forward quickly. "In the area of human germline editing technology, we have already stepped to the forefront," researcher Liu Jian-Qiao wrote a few months ago. Liu said that research should be "bounded" by international norms established in 2015, but that China should also influence those standards: "We should … strive for more of a right to have our voices heard, and for greater authority to take initiative in the area of clinical applications research."

In China, there wasn't the same reluctance as in the US to think about the technology's benefits. The embryo-editing teams I interviewed were all clearly preparing the technology for eventual use in humans. Some of them, for instance, were attempting to locate cases where—in line with the US National Academy of Sciences' criteria for using CRISPR—germline gene editing might be the only answer. One such scientist was Fan Yong, who like Huang is based in Guangzhou. "We are currently mainly selecting diseases that can only be cured by using embryonic gene editing treatments," he wrote in an e-mail. One candidate group Fan was exploring is deaf men and women who marry, a common occurrence in a country as large as China. If both parents' hearing loss has the same genetic cause, it can mean they can't have a hearing child. Fan told me he thinks correcting deafness in embryos "is a natural choice for public health in China."

Still, none of the Chinese scientists I spoke to said they thought a

baby was coming anytime soon. They noted that under a 2003 government guideline, no IVF clinic was supposed to take a genetically modified embryo and start a pregnancy. "From the perspective of technology as well as how society would accept it, I don't think we're at that point yet," Huang told me when I visited with him. Maybe one day, he said, when the technology was more advanced.

TOO LATE

In Shenzhen, He wasn't waiting.

It appears that by about February 2018, He's team had transferred edited embryos into the uterus of a woman (who remains unidentified). They continued to monitor the pregnancy, taking blood draws and peering at the twins' genomes that way. It remains unclear what authorities—if any—in China signed off on the trial. He's own university now claims it knew nothing about the study, which was carried out quietly if not secretly.

He may have planned to make his big reveal of the CRISPR babies in November during the Second International Summit on Human Genome Editing in Hong Kong, a meeting whose purpose was to debate the prospect of making such babies, and where he was among some 70 scheduled speakers. "I suspect he was planning to pull a Steve Jobs–style 'one last thing' during his talk," says Musunuru, referring to the Apple founder's trick of saving the biggest news for last. It would be the ultimate fait accompli—a "bombshell" set off before the world. Instead, reports of He's undertaking leaked just before the meeting, and the scientist rushed to post a series of recorded statements to YouTube. The twins were named Lulu and Nana. "We hope you have mercy for them," He said. "I believe families need this technology."

Oversight? It's unclear if there was much. A daring cure? Not really. HIV can be treated or prevented with other, cheaper methods and still affects less than 0.1% of the population in China. As David Liu, a Harvard biologist, asked He in Hong Kong: "What is the unmet medical need?" The question cut to the quick—in medicine, risky interventions for healthy people are unacceptable. The embryos He chose to edit were normal.

"When I realized what had happened, I screamed—literally," says Musunuru, who has seen the genetic readouts on the embryos that had turned into the twin girls. There had been "a mess of different edits"—that is, cells were changed in different ways. The girls may prove to be made up of a mosaic of differently edited cells as well. "The first gene-edited baby was going to be a disturbing event, no matter what," he says. "The fact that it happened this way, with flawed embryos, by researchers who were either clueless about the problem or simply couldn't care less, made it 100 times worse."

"The first gene-edited baby was going to be a disturbing event, no matter what. The fact that it happened this way, with flawed embryos, by researchers who were either clueless about the problem or simply couldn't care less, made it 100 times worse."

The criticisms after He announced the births were unrelenting. "Beyond belief," said Feng Zhang, of the Broad Institute, another of CRISPR's co-inventors. Huang weighed in with a statement that what his counterpart had done was "against the law, regulation, and medical ethics of China."

Some scientists, it turns out, were in the know about He's work. One can only guess why they remained silent. But we know how the He affair ended in Hong Kong. George Daley, the dean of Harvard Medical School and the same person who implied a few years back that Huang wasn't right in the head, took the stage and, though he called He's work a "misstep," did not condemn it. Instead, Daley spoke in favor of using CRISPR in IVF clinics in the future, saying it was time to move past the question of "ethical permissibility" and on to the question of how to do it correctly.

In their final statement, summit leaders gave no mention to a criterion they had once agreed was paramount before moving into clinical applications: "broad societal consensus." There is no consensus yet about whether we should engineer human beings—and there may never be. But He's claim helped make the question moot. We already have.

It's unclear what will happen to He. His clinical trial was halted, and the government seems about equally likely to block any further babies as to endorse them. He left the Hong Kong conference early, saying he would "remain in China, my home country, and cooperate fully with all inquiries about my work."

Huang, meanwhile, went back to Guangzhou and is continuing his research. In our interview, which occurred before the announcement of the CRISPR babies, I had asked him whether he would do anything differently if he could go back in time. Would he put CRISPR in a human embryo? "I would do it again," he said. "The development of science and technology is unavoidable."

Antonio Regalado is a senior editor at MIT Technology Review.

THE CALTECH OF CHINA

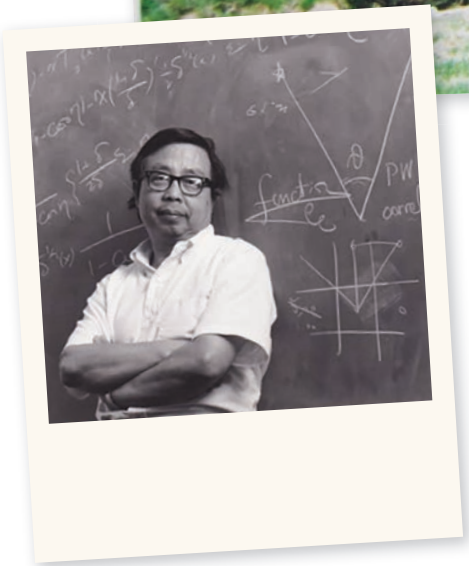
Can science transcend politics?

By Yangyang Cheng

On a hot late-summer day in 2005, I sat in a packed, agreeably air-conditioned auditorium and listened to a university administrator welcome the class of 2009. "Congratulations! As the popular saying goes, 'The rich go to Peking U, the poor go to Tsinghua, and the ones willing to work themselves to death come to USTC.'"

We laughed. If Peking University is China's Harvard, and Tsinghua is China's MIT, the University of Science and Technology of China, or USTC, is known as "the Caltech of China" for its small size and intense focus on science and engineering. I was proud to be there. But my pride shifted to awkwardness after the speech, when we stood to sing the university anthem, which ends with an exhortation: "Always learn from the people, and learn from the great leader Mao Zedong!"

Hearing Mao's name left a bitter taste. It reminded me of career paths my country had denied me. Without the rule of law, I could not become a lawyer. Without a free press, I could not become a journalist. Without democratic



1980
Fang Lizhi, one of USTC's first faculty members, was later forced into exile in the US.

1993
The author holds her father´s PhD diploma at his graduation ceremony.

1963
USTC´s first graduation ceremony, in Beijing.

FAMILY PHOTO / USTC

elections, I could not become a politician. Instead I did what was expected of Chinese students without political connections or financial resources but with impeccable grades: I came to USTC to study science.

The lyrics of the anthem brought up a question my classmates and I would often ponder: Must scientific research be in service of one's country—or can the pursuit of knowledge transcend nationalism?

Generations of scientists at USTC have sought to answer this question. The university gave birth to both China's first satellite, launched in 1970, and the world's first quantum-communication satellite, launched in 2016 (see story on page 56). It is home to China's first synchrotron particle accelerator, and it will soon host a new multibillion-dollar quantum-science center. Over the years, faculty and students have, at times, wielded the university's scientific prestige as a shield to protect academic freedom and political independence.

But if the university's rising trajectory in recent years is any indication, science in China thrives most when it serves the state. Today I live and work in the United States. I spoke to many old schoolmates and current USTC researchers to report this article. The story of USTC that emerges reveals the limits of science's ability to transcend China's authoritarian politics.

It is also the story of my family across three generations.

When the Cultural Revolution arrived in 1966, science was deemed heresy and knowledge was considered counterrevolutionary. Schools were closed. Books were burned.

USTC WAS FOUNDED IN BEIJING IN 1958, TO train scientists for China's fledgling nuclear and space programs. Members of the faculty were drawn from China's scientific elite. Fang Lizhi, one of the first, came to teach physics after being deemed too politically outspoken to work on the bomb. "He was actually happy about it! He said he would rather not work on killer weapons," Fang's widow, Li Shuxian, told me.

When the Cultural Revolution arrived in 1966, science was deemed heresy and knowledge was considered counterrevolutionary. Schools were closed. Books were burned.

USTC's central contribution to national defense did little to shield it. The university was forced to leave Beijing in 1969, at the height of the Cultural Revolution, and struggled to find a new home. Nobody wanted a group of intellectuals moving to town. Multiple provinces cited lack of food as an excuse before Anhui, one of the poorest, eventually agreed to host the university. The academic departments were scattered across the province: the Department of Modern Physics, known to have the most independent-minded students, was sent to a remote military farm. Only Modern Mechanics, run by Qian Xuesen, known as the "father of Chinese rocketry," was placed in Hefei, the provincial capital.

That was where USTC's and my family's fates first intersected.

My grandfather had moved to Hefei a decade earlier to teach at the provincial Communist Party school. As the fever of the Cultural Revolution broke, classes at USTC partially resumed in 1972. Despite political pressure, Fang, the physicist, established China's first astrophysics group at USTC. In 1973, my grandfather became a faculty member at USTC's small humanities and social sciences division, where he taught economics for the rest of his life.

All my grandfather ever said to me about the Cultural Revolution was: "I was sent to labor. Everyone needed to labor!" His lack of interest in politics probably spared him the worst. Many of his more politically engaged and outspoken classmates and colleagues were dealt a harsher fate. "All of them died! All of them were tortured to death!" remembers Fang's widow, listing off luminaries who had laid the foundation of modern science in China. "Zhao Jiuzhang died. Ye Qisun died. Wang Zhuxi, who taught me statistical mechanics, died. Only Qian Xuesen fared okay."

After Mao's death in 1976, the central government sensed an urgent need to rebuild the science and technology sector. When regular university admissions in China resumed in 1977, USTC had first pick: no matter which university a student applied to, the ones with the best grades in the sciences were sent there.

"The university was very poor, and in retrospect the conditions were very difficult," a senior physicist at USTC who was then a student told me. (He requested anonymity out of concern for political blowback

from speaking with a foreign magazine.) Seven students shared a single, cramped dorm room. Like most of his classmates, the physicist had spent years of his youth working at farms and factories during the Cultural Revolution, and he wanted to go back to school more than anything. "We read while walking. We read while standing in line for food," he says. "Every day at the break of dawn, you could find students reading English by the streetlights."

By the early '80s, following Deng Xiaoping's rise to power, Fang had been politically rehabilitated. In 1984 he became executive vice president of USTC. Guan Weiyan, a fellow physicist, was president. Describing his ambitions for the institution, Fang said, "A university should be filled with the spirit of science, democracy, creativity, and independence." For a time, it seemed as though Guan and Fang's leadership of USTC might transform the nation.

It was not to be. In December 1986, a few days before local elections, Fang gave a speech, saying, "I do not think democracy is bestowed from the top down. It is fought for from the bottom up." Thousands of students protested the next day in Hefei, which then inspired more protests around China. Though they tried to defuse the student demonstrations, Fang and Guan were fired. The student movement continued until tanks rolled into Tiananmen Square in June 1989, killing thousands of protesters.

Fang and Li, his wife, took refuge in the US embassy in Beijing. They remained there for 13 months, until the American and Chinese governments negotiated a deal allowing them to go into exile in the United States. Neither ever returned.

Their names remain taboo in China. All of their published writings remain banned. Nonetheless, their legacy remains a source of forbidden pride for many at USTC. At the news of Fang's death in 2012, messages of remembrance from alumni filled social media and electronic bulletin boards.

USTC HAD BEEN BY FAR THE MOST SELECTIVE university in China before Fang and Guan's dismissal. After they were pushed out, it retained a rigorous curriculum and was still tough to get into, but the sense of punishment was palpable. Funding was cut. Recruiting of students and faculty suffered. It didn't help that Hefei was left behind as Beijing and other metropolises like Shanghai and Shenzhen began to prosper.

Deng Xiaoping's aphorism "Let a small number of people get rich first!" became a sort of unofficial motto for China's economic transformation. I was born in the fall of 1989, months after the Tiananmen massacre. By the time my father got his PhD at USTC in 1993, Jiang Zemin, Deng's successor, had again rehabilitated the university.

My father's graduation ceremony, held on USTC's central square, is one of my most cherished memories. I wore the only dress I owned, a frilly number with notes of lace, fancy for the time. In a grainy family photo, my father's black-and-red robe contrasts with the green pine trees behind him. He holds me high in his arms, while I hug his hard-earned diploma tightly. My mother stands next to us. A tall stone plaque to our left is engraved with a handwritten message from USTC's founding president: "Study hard. Be red. Be expert!"

That same year Chen Xiaoping, who now directs USTC's Center for Artificial Intelligence Research, arrived at the university to work on his own PhD. "Very few people were studying AI in China at the time. And it was mostly theoretical," he says. When he left China for the first time to attend an AI conference in Stockholm in 1999, only one other scientist from mainland China was there.

1970s USTC students laboring in Hefei during the Cultural Revolution.

Fang and his fellow physicist wife, Li Shuxian.

FANG FAMILY; USTC

But by the late 1990s, computer science was exploding as a field of study in China and elsewhere. A six-person team of USTC students, led by Liu Qingfeng, won a national voice-synthesis technology competition held in 1998 as part of a government effort to help the explosion along.

Microsoft Research China tried to hire Liu, but he convinced his teammates to found their own company. They named it iFlytek. The company struggled in its early years. Liu was just 26 when it launched, and while he recognized the potential for voice recognition and synthesis technology, he lacked managerial experience. The company nearly collapsed.

At a fateful meeting in 2000, some suggested that they change direction and go into commercial real estate, in light of the construction boom in China. "We made a choice that we would still make today," Liu said in a TV interview years later. "We said, if you do not have confidence in voice recognition technology, please leave." The founder of Lenovo saved them with a last-minute injection of capital. iFlytek now employs over 10,000 people; hundreds of millions of customers use its speech recognition software daily. The company is worth over $2 billion.

By the time I graduated from USTC in 2009 with a physics degree and the goal of becoming an experimental particle physicist, Hefei was transforming before my eyes. If it had lagged behind coastal areas in the 1990s, by the first decade of this century it was catching up with alacrity. The city doubled and tripled in size. New manufacturing plants, shopping malls, and commercial real estate sprouted up everywhere. As it grew, so did USTC. The university added new dorms, teaching buildings, research centers, and campuses and a second national laboratory.

What had been founded as a training ground for scientists working on atomic weapons now became an incubator for China's high-tech industry. iFlytek was only the first of a series of big companies that USTC alumni would start. SenseTime, an AI firm now worth almost $5 billion, was founded by a USTC grad. Another would go on to run Baidu, the search giant. Yet these companies and others like them, whether in computer science or in biotech, illustrate the ethical quandaries facing scientists in an authoritarian state.

IN A FEW SHORT YEARS, THE CHINESE GOVERNment has turned the northwestern region of Xinjiang into a 21st-century police state with high-tech surveillance and mass collection of biometric data. The government is holding over a million members of the Uighur and Kazakh minorities, most of them ethnic Muslims, in concentration camps. Human Rights Watch describes the situation in Xinjiang as the worst human-rights crisis in China since the Cultural Revolution.

Many of the technologies that facilitate oppression in Xinjiang come out of work done at USTC. And many of them are now being used elsewhere in China. iFlytek is collaborating with Chinese authorities to build a nationwide voice-based surveillance system.

The Chinese government has tightened its authoritarian grip since Xi Jinping took office in 2012. "The management at USTC had always been relatively loose, up until about a year or so ago," says the senior physicist. "Things are more sensitive now. No one knows what will happen next."

"An individual scientist has little power to change government policy," says Li, Fang's widow, "but if an authoritarian government asks a scientist to serve its interests, the scientist has the power to

"An individual scientist has little power to change government policy," says Li, Fang's widow, "but if an authoritarian government asks a scientist to serve its interests, the scientist has the power to make a choice."

make a choice." I made my choice almost 10 years ago, when I left China to come to the US for graduate school. I told my family that I was going across the ocean not just to pursue a degree in science but also to live in a free country.

Over the past few years, I've often traveled to Washington, DC, to meet with members of Congress and the executive branch to advocate for federal support of basic research. It's both humbling and empowering to do so—to feel that I can take part in American democracy even as a new arrival to this country. But as the Trump administration has become increasingly hostile and discriminatory to immigrants, women, and people of color—all of which I am—it has become increasingly difficult for me to conscientiously ask for funding from a government that discounts my humanity, or the humanity of any group of people.

CHINESE ACADEMICS IN THE UNITED STATES face a dilemma: try to stay in a country where our future is increasingly in doubt, or go back to one that demands we choose between moral compromise and martyrdom.

The Chinese government has launched aggressive campaigns to attract overseas talent. Recent USTC presidents have crisscrossed North America on recruiting trips. I called He Yu, an old classmate of mine who had just received his PhD in physics from Stanford, to ask how he felt. "I just had this debate with two of my classmates, who were telling me to never go back to China," he said.

We have known one another for more than half our lives. We spoke for a long time—about the history of the atomic bomb, about how Google pulled out of US defense contracts while developing a censored search engine in China, and about iFlytek's work in Xinjiang. We contemplated our privilege and security in being able to discuss these topics openly and freely.

"At the end of the day, it is a compromise between complicity and survival," said He. "Our view of what is right or wrong is from 6,000 miles away. It's a different view for students and researchers on campus."

The plaque at USTC is still there: "Study hard. Be red. Be expert."

He's work focuses on superconductivity. "I'm torn at times," he said, going on to list applications of the technology that have potential for both civilian and military use. "We always say 'for the greater good,' but who's to determine what the greater good is?"

"I don't have a good answer for you," I replied. "That's partly why I chose not to study applied science." It was an honest answer, but it made me feel like a hypocrite.

USTC marked its 60th anniversary in September 2018. A flurry of events celebrated the university's legacy in building China's nuclear and space programs, as well as its strides in quantum computing and artificial intelligence. The celebration culminated in a gala on the evening of September 20, USTC's official birthday.

A grand stage was constructed on campus next to the main entrance. Current and former students poured in from across the globe. I watched a recording a few days later. Students in military uniforms sang ballads in front of Maxwell's equations. Alumni who are now generals in the People's Liberation Army sat in the front row and gave remarks. This was followed by a segment called "Humans dancing with machines," which featured students moving mechanically on stage with a group of R2-D2 look-alikes. The robots, like the students, were products of USTC: they were built by UBTech, a leading Chinese robotics company headed by USTC alumni.

The evening concluded with everyone standing to sing the university anthem: "Greetings to the eternal east wind/Raise the red flag high!" I had been chuckling and shaking my head at the stilted robot dance. But as the familiar melody came through my computer's speakers, tears flooded my eyes. I replayed the last few minutes of the video again and again, sobbing uncontrollably in my room, an ocean away.

Growing up on USTC's campus, I'd heard this song on the radio every weekday at noon for the first 19 years of my life. As a child, I knew it signaled lunchtime. I'd go to the window to watch streams of people emerge from labs and classrooms into apartment buildings or the campus canteen, trying hard to spot my parents. When I first learned its lyrics in elementary school, I had asked my mother why it was so political. My mother said the song was a creation of its time.

Over the years the political has faded into the personal. The song, and the place it represents, are etched into me. USTC is where my grandfather lived and worked and died. USTC is where my father lived and worked and died. USTC is where my mother grew up. USTC is where I grew up. USTC is the home I left with no certain prospect of return. The scientists of USTC have harnessed the power that fuels the stars, yet still find themselves powerless against the changing tides of politics.

I asked each of the people I interviewed for this story what they thought of USTC's anniversary slogan, "Sixty years of being red and being expert. Sixty years of science and education in service of the state." Did they think the purpose of science is to serve the state?

None said yes. One USTC professor, a prominent physicist, replied by quoting Mencius, an ancient philosopher: "In straitened circumstances, they perfected their own virtues in solitude. In prosperous times, they aided all under heaven impartially."

Yangyang Cheng is a postdoctoral research associate at Cornell University and a member of the CMS experiment at the Large Hadron Collider.

YIMING CHEN / GETTY

Fintech has transformed daily life in China. Here are five reasons it won't do the same in the West anytime soon.

By **Martin Chorzempa**

A payment apps paradise

In 2013 I moved from Paris to Beijing to study China's financial system. I stayed for two years and became fluent enough to translate economics books from Mandarin into English and give talks on monetary policy in Mandarin.

But I never really felt I fit in until I visited again and Alipay finally approved me (foreigners can have a hard time getting authorized to use China's financial super-apps). Before then, I would frantically search for an ATM for cash while my friends used their phones' Alipay or WeChat apps—similar to Venmo—to split restaurant bills. They invested their paychecks with the click of a button to start earning interest immediately, while I had to wait in line at a bank. But last year, armed with Alipay, I used a shared bike that got me to a meeting early, paid for dinner by scanning a QR code, and then called my first ride-share via Didi—all through the app.

Ant Financial's Alipay and Tencent's WeChat have changed the way many people live their financial lives. They are one-stop shops that enable half a billion Chinese to access a dizzying array of services, from payments, loans, investments, and credit scores to taxi rides, travel bookings, and social media.

Martin Chorzempa is a research fellow at the Peterson Institute for International Economics in Washington, DC. He's also a former visiting scholar at Peking University's China Center for Economic Research.

Because so much is sold via these apps, Alibaba and Tencent know the health (or lack thereof) of many small businesses across China. As a result, they can lend to companies that banks might consider too risky. Likewise, people with no traditional credit score can get cheap loans because Ant Financial has their payment and purchase history.

In the United States, meanwhile, people overwhelmingly pay with plastic and write out billions of paper checks every year. Facebook makes users switch between two separate apps for messaging and scrolling through friends' feeds. Google Wallet launched in 2011, two years before Alipay's digital wallet, but it languishes mostly unused. Apple Pay came out a year later, but it can be difficult to find retailers that accept it even in major US cities.

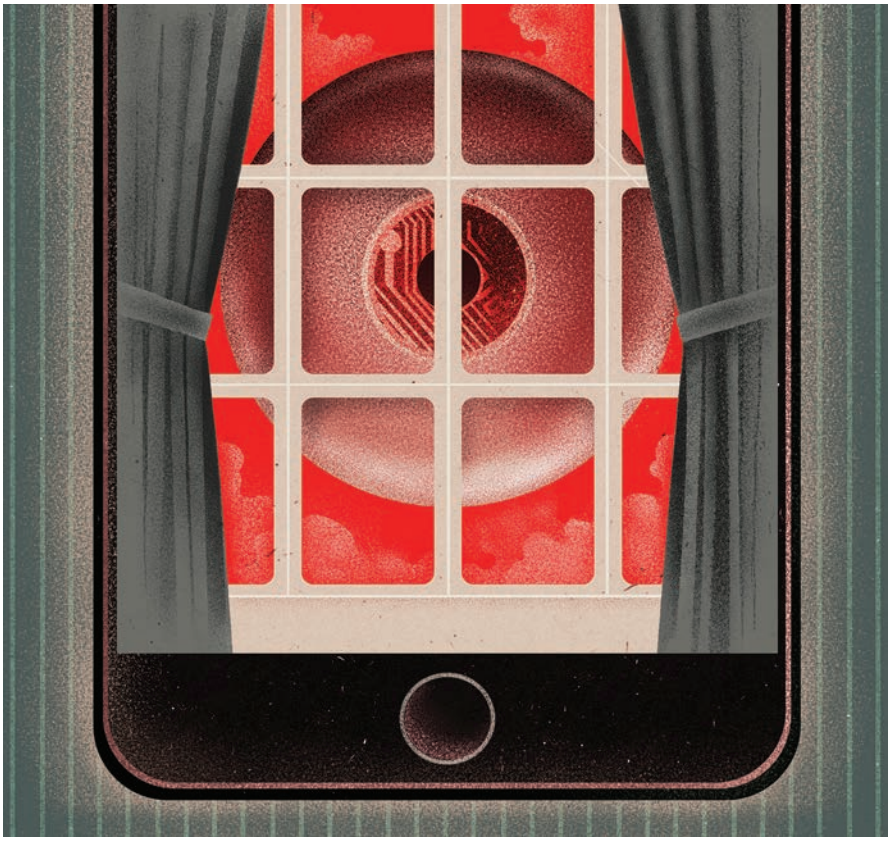
So with all the advantages, is the West just a few years away from gleefully adopting the Chinese model? Probably not. Here's why.

1 China was ripe for a payments revolution because alternatives didn't exist

In 2004, when Alipay launched as a simple payment option, Chinese finance was extremely low-tech. Clunky state-owned banks had nearly gone bankrupt from bad loans, and they cared little for average consumers. People had to travel to bank branches and wait in long lines to pay their bills; savings were eroded because the government set the interest rate on deposits below inflation; and barely anyone could get a credit card. Only 7.3% of Chinese used the internet then, compared with 65% of Americans.

So when something new came along, there were barely any legacy systems to get in the way. Fintech firms had room to grow instead of being squashed or acquired by giant incumbents.

Compare that with the US, where traditional financial firms have long provided decent options for loans, payments, and investments. Any fintech startup in the US that wants to get into payments has to go up against Visa and Mastercard, which



EOIN RYAN

Ant Financial and Tencent control far more and see into more of their users' lives than any individual companies in the US do. That information could be used against you.

benefit from decades of experience and ingrained consumer habits.

2 The innovations that sparked Chinese fintech were nothing new outside China

Many of China's highly touted fintech "innovations" were in fact adaptations, combinations, or more successful uses of technology or models pioneered by others. QR codes were used in Japanese supply chains starting in 1994, escrow services were long available on eBay, and money market funds that allowed users to invest via electronic payment accounts were available on PayPal all before Alipay used QR codes for payment and launched China's fintech frenzy with its Yu'E Bao money market fund. For all the hype about mobile payments, most Alipay and Tencent Pay transactions today actually have digital versions of old-fashioned debit cards hiding behind the QR codes. And the codes themselves can hide malware that drains people's bank accounts.

3 The Chinese system is a hacker's dream and a privacy nightmare

The convenience of sharing your account data only once, with one app, not only gives the payment platforms enormous power but also makes them gigantic honeypots for hackers. We've seen what happens when we put excessive trust in firms to secure multiple areas of our lives—like using Facebook to log in to other websites. A similar issue with Ant Financial or Tencent would be far worse. They control far more and see into more of their users' lives than any individual companies in the US do. That information could be used against you—for example, they could get you to pay more if they think you'd be willing to.

4 Chinese fintech got a major helping hand from the government

The Chinese government gave its tech giants far more leeway to innovate than American regulators would allow. China left the online payments market virtually unregulated for years, and the central bank governor explicitly stated that he would allow unregulated tech firms to enter spaces that were previously off limits to anyone without a financial license, giving those companies freedom to grow before any rules would be imposed.

For better or worse, US regulators took the opposite approach. They forced young fintech startups to comply with the full rulebook, though its application to their new models was not always clear. For example, PayPal had to go state by state to apply for money transmitter licenses. The US has also long kept a separation between banking and nonfinancial businesses. If Google wanted to own a bank, American regulators would force it to get out of businesses like search and advertising. This may bar American tech from ever pursuing China's super-app model.

5 Fintech shuts out the elderly and the less tech-savvy

As I found out the hard way, if you're a foreigner—or if you're a tourist, or you're from rural China, or you're older and used to dealing with cash—you can get shut out by an app-focused economy. People are finding their cash unwelcome all over China, and they might discover that they can't get a taxi because it's already been hailed by someone with an app.

So while there's lots to like about the Chinese model, especially its convenience, we might not actually want to emulate it—even if we could.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Locked out of the Chinese room

How China took on Google—and won.

By Matt Sheehan
Illustrations by Stuart Bradford

Google's first foray into Chinese markets was a short-lived experiment. Google China's search engine was launched in 2006 and abruptly pulled from mainland China in 2010 amid a major hack of the company and disputes over censorship of search results. But in August 2018, the investigative journalism website The Intercept reported that the company was working on a secret prototype of a new, censored Chinese search engine, called Project Dragonfly. Amid a furor from human rights activists and some Google employees, US Vice President Mike Pence called on the company to kill Dragonfly, saying it would "strengthen Communist Party censorship and compromise the privacy of Chinese customers."

Observers talk as if the decision about whether to reenter the world's largest market is up to Google: will it compromise its principles and censor search the way China wants? This misses the point—this time the Chinese government will make the decisions.

Google and China have been locked in an awkward tango for over a decade, constantly grappling over who leads and who follows. Charting that dance over the years reveals major shifts in China's relationship with Google and all of Silicon Valley. To understand whether China will let Google back in, we must understand how Google and China got here, what incentives each party faces—and how artificial intelligence might have both of them dancing to a new tune.

The right thing to do?

When www.google.cn launched in 2006, the company had gone public only two years before. The iPhone did not yet exist, nor did any Android-based smartphones. Google was about one-fifth as large and valuable as it is today, and the Chinese internet was seen as a backwater of knockoff products that were devoid of innovation. Google's Chinese search engine represented the most controversial experiment to date in internet diplomacy. To get into China, the young company that had defined itself by the motto "Don't be evil" agreed to censor the search results shown to Chinese users.

Central to that decision by Google leadership was a bet that by serving the market—even with a censored product—they could broaden the horizons of Chinese users and nudge the Chinese internet toward greater openness.

At first, Google appeared to be succeeding in that mission. When Chinese users searched for censored content on google.cn, they saw a notice that some results had been removed. That public acknowledgment of internet censorship was a first among Chinese search engines, and it wasn't popular with regulators.

"The Chinese government hated it," says Kaiser Kuo, former head of international communications for Baidu. "They compared it to coming to my house for dinner and saying, 'I will agree to eat the food, but I don't like it.'" Google hadn't asked the government for permission before implementing the notice but wasn't ordered to remove it. The company's global prestige and technical expertise gave it leverage. China might be a promising market, but it was still dependent on Silicon Valley for talent, funding, and knowledge. Google *wanted* to be in China, the thinking went, but China *needed* Google.

MIT Technology Review

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Kent Walker
Senior Vice President of Global Affairs and Chief Legal Officer, Google

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Google's censorship disclaimer was a modest victory for transparency. Baidu and other search engines in China soon followed suit. Over the next four years, Google China fought skirmishes on multiple fronts: with the Chinese government over content restrictions, with local competitor Baidu over the quality of search results, and with its own corporate leadership in Mountain View, California, over the freedom to adapt global products for local needs. By late 2009, Google controlled more than a third of the Chinese search market—a respectable share but well below Baidu's 58%, according to data from Analysys International.

In the end, though, it wasn't censorship or competition that drove Google out of China. It was a far-reaching hacking attack known as Operation Aurora that targeted everything from Google's intellectual property to the Gmail accounts of Chinese human rights activists. The attack, which Google said came from within China, pushed company leadership over the edge. On January 12, 2010, Google announced, "We have decided we are no longer willing to continue censoring our results on Google.cn, and so over the next few weeks we will be discussing with the Chinese government the basis on which we could operate an unfiltered search engine within the law, if at all."

The sudden reversal blindsided Chinese officials. Most Chinese internet users could go about their online lives with few reminders of government controls, but the Google announcement shoved cyberattacks and censorship into the spotlight. The world's top internet company and the government of the most populous country were now engaged in a public showdown.

"[Chinese officials] were really on their back foot, and it looked like they might cave and make some kind of accommodation," says Kuo. "All of these people who apparently did not give much of a damn about internet censorship before were really angry about it. The whole internet was abuzz with this."

But officials refused to cede ground. "China welcomes international Internet businesses developing services in China according to the law," a foreign ministry spokeswoman told Reuters at the time. Government control of information was—and remains—central to Chinese Communist Party doctrine. Six months earlier, following riots in Xinjiang, the government had blocked Facebook, Twitter, and Google's YouTube in one fell swoop, fortifying the "Great Firewall." The government was making a bet: China and its technology sector did not need Google search to succeed.

Google soon abandoned google.cn, retreating to a Hong Kong–based search engine. In response, the Chinese government decided not to fully block services like Gmail and Google Maps, and for a while it allowed sporadic access from the mainland to the Hong Kong search

engine too. The two sides settled into a tense stalemate.

Google's leaders seemed prepared to wait it out. "I personally believe that you cannot build a modern knowledge society with that kind of [censorship]," Google chairman Eric Schmidt told Foreign Policy in 2012. "In a long enough time period, do I think that this kind of regime approach will end? I think absolutely."

Role reversal

But instead of languishing under censorship, the Chinese internet sector boomed. Between 2010 and 2015, there was an explosion of new products and companies. Xiaomi, a hardware maker now worth over $40 billion, was founded in April 2010. A month earlier Meituan, a Groupon clone that turned into a juggernaut of online-to-offline services, was born; it went public in September 2018 and is now worth about $35 billion. Didi, the ride-hailing company that drove Uber out of China and is now challenging it in international markets, was founded in 2012. Chinese engineers and entrepreneurs returning from Silicon Valley, including many former Googlers, were crucial to this dynamism, bringing world-class technical and entrepreneurial chops to markets insulated from their former employers in the US. Older companies like Baidu and Alibaba also grew quickly during these years.

The Chinese government played contradictory roles in this process. It cracked down on political speech in 2013, imprisoning critics and instituting new laws against "spreading rumors" online—a one-two punch that largely suffocated political discussion on China's once-raucous social-media sites. Yet it also launched a high-profile campaign promoting "mass entrepreneurship and mass innovation." Government-funded startup incubators spread across the country, as did government-backed venture capital.

That confluence of forces brought results. Services like Meituan flourished. So did Tencent's super-app WeChat, a "digital Swiss Army knife" that combines aspects of WhatsApp, PayPal, and dozens of other apps from the West. E-commerce behemoth Alibaba went public on the New York Stock Exchange in September 2014, selling $25 billion worth of shares—still the most valuable IPO in history.

Amidst this home-grown success, the Chinese government decided to break the uneasy truce with Google. In mid-2014, a few months before Alibaba's IPO, the government blocked virtually all Google services in China, including many considered essential for international business, such as Gmail, Google Maps, and Google Scholar. "It took us by surprise, as we felt Google was one of those valuable properties [that they couldn't afford to block]," says Charlie Smith, the pseudonymous cofounder of GreatFire, an organization that tracks and circumvents Chinese internet controls.

The Chinese government had pulled off an unexpected hat trick: locking out the Silicon Valley giants, censoring political speech, and still cultivating an internet that was controllable, profitable, and innovative.

The Chinese government cracked down on political speech in 2013, imprisoning critics and instituting new laws against "spreading rumors" online—a one-two punch that suffocated political discussion.

AlphaGo your own way

With the Chinese internet blossoming and the government not backing down, Google began to search for ways back into China. It tried out less politically sensitive products—an "everything but search" strategy—but with mixed success.

In 2015, rumors swirled that Google was close to bringing its Google Play app store back to China, pending Chinese government approval—but the promised app store never materialized. This was followed by a partnership with Mobvoi, a Chinese smart-watch maker founded by an ex-Google employee, to make voice search available on Android Wear in China. Google later invested in Mobvoi, its first direct investment in China since 2010.

In March 2017, there were reports that authorities would allow Google Scholar back in. They didn't. Reports that Google would launch a mobile-app store in China together with NetEase, a Chinese company, similarly came to naught, though Google was permitted to relaunch its smartphone translation app.

Then, in May 2017, a showdown between AlphaGo, the Go-playing program built by Google sibling company DeepMind, and Ke Jie, the world's number one human player, was allowed to take place in Wuzhen, a tourist town outside Shanghai. AlphaGo won all three games in the match—a result that the government had perhaps foreseen. Live-streaming of the match within China was forbidden, and not only in the form of video: as the Guardian put it, "outlets were banned from covering the match live in any way, including text commentary, social media, or push notifications." DeepMind broadcast the match outside China.

During this same period, Chinese censors quietly rolled back some of the openings that Google's earlier China operations had catalyzed. In 2016, Chinese search engines began removing the censorship disclaimers that Google had pioneered. In 2017, the government launched a new crackdown on virtual private networks (VPNs), software widely used for circumventing censorship. Meanwhile, Chinese authorities began rolling out extensive AI-powered surveillance technologies across the country, constructing what some called a "21st-century police state" in the western region of Xinjiang, home to the country's Muslim Uighurs.

Despite the retrograde climate, Google capped off 2017 with a major announcement: the launch of a new AI research center in Beijing. Google Cloud's Chinese-born chief scientist, Fei-Fei Li, would oversee the new center. "The science of AI has no borders," she wrote in the announcement of the center's launch. "Neither do its benefits." (Li left Google in September 2018 and returned to Stanford University, where she is a professor.)

If the research center was a public symbol of Google's continued efforts to gain a foothold in China, Google was also working quietly to accommodate Chinese government restrictions. Dragonfly, the censored-search-engine prototype, which has been demonstrated for Chinese officials, blacklists key search terms; it would be operated as part of a joint venture with an unnamed Chinese partner. The documents The Intercept obtained said the app would still tell users when results had been censored.

Other aspects of the project are particularly troubling. Prototypes of the app reportedly link users' searches to their mobile-phone number, opening the door to greater surveillance and possibly arrest if people search for banned material.

In a speech to the Dragonfly team, later leaked by The Intercept, Ben Gomes, Google's head of search, explained Google's aims. China, he said, is "arguably the most interesting market in the world today." Google was not just trying to make money by doing business in China, he said, but was after something bigger. "We need to understand what is happening there in order to inspire us," he said. "China will teach us things that we don't know."

The question is, now that Google wants to come back to China, does China want to let it in?

China's calculus

To answer that question, try thinking like an advisor to President Xi Jinping.

Bringing Google search back certainly has upsides. China's growing number of knowledge workers need access to global news and research, and Baidu is notoriously bad at turning up relevant results from outside China. Google could serve as a valuable partner to Chinese companies looking to expand internationally, as it has demonstrated in a patent-sharing partnership with Tencent and a $550 million investment in e-commerce giant JD. Google's reentry would also help legitimize the Communist Party's approach to internet governance, a signal that China is an indispensable market—and an open one—as long as you "play by the rules."

But from the Chinese government's perspective, these potential upsides are marginal. Chinese citizens who need to access the global internet can still usually do so through VPNs (though it is getting harder). Google doesn't need to have a business in China to help Chinese internet giants gain business abroad. And the giants of Silicon Valley have already ceased

In 2017, the government launched a new crackdown on virtual private networks, software widely used for circumventing censorship.

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Google's exit in 2010 marked a major loss of face for the Chinese government. If leaders give the green light to Project Dragonfly, they run that risk again.

their public criticism of Chinese internet censorship, and instead extol the country's dynamism and innovation.

By contrast, the political risks of permitting Google to return loom large to Xi and his inner circle. Hostility toward both China and Silicon Valley is high and rising in American political circles. A return to China would put Google in a political pressure cooker. What if that pressure—via antitrust action or new legislation—effectively forced the company to choose between the American and Chinese markets? Google's sudden exit in 2010 marked a major loss of face for the Chinese government in front of its own citizens. If Chinese leaders give the green light to Project Dragonfly, they run the risk of that happening again.

A savvy advisor would be likely to think that these risks—to Xi, to the Communist Party, and to his or her own career—outweighed the modest gains to be had from allowing Google's return. The Chinese government oversees a technology sector that is profitable, innovative, and driven largely by domestic companies—an enviable position to be in. Allowing Google back in would only diminish its leverage. Better, then, to stick with the status quo: dangle the prospect of full market access while throwing Silicon Valley companies an occasional bone by permitting peripheral services like translation.

Google's gamble

Google does have one factor in its favor. If it first entered China during the days of desktop internet, and departed at the dawn of the mobile internet, it is now trying to reenter in the era of AI. The Chinese government places high hopes on AI as an all-purpose tool for economic activity, military power, and social governance, including surveillance. And Google and its Alphabet sibling DeepMind are the global leaders in corporate AI research.

This is probably why Google has held publicity stunts like the AlphaGo match and an AI-powered "Guess the Sketch" game on WeChat, as well as taking more substantive steps like establishing the Beijing AI lab and promoting Chinese use of TensorFlow, an artificial-intelligence software library developed by the Google Brain team. Taken together, these efforts constitute a sort of artificial-intelligence lobbying strategy designed to sway the Chinese leadership.

This pitch, however, faces problems on at least three battlegrounds: Beijing; Washington, DC; and Mountain View, California.

Chinese leaders have good reason to feel they're already getting the best of both worlds. They can take advantage of software development tools like TensorFlow and they still have a prestigious Google research lab to train Chinese AI researchers, all without granting Google market access.

In Washington, meanwhile, American security officials are annoyed that Google is actively courting a geopolitical rival while refusing to work with the Pentagon on AI projects because its employees object to having their work used for military ends.

Those employees are the key to the third battleground. They've demonstrated the ability to mobilize quickly and effectively, as with the protests against US defense contracts and a walkout last November over how the company has dealt with sexual harassment. In late November more than 600 Googlers signed an open letter demanding that the company drop the Dragonfly project, writing, "We object to technologies that aid the powerful in oppressing the vulnerable." Daunting as these challenges sound—and high as the costs of pursuing the Chinese market may be—they haven't yet deterred Google's top brass. But the wealth and dynamism that make China so attractive to Google also mean the decision is no longer the company's to make.

"I know people in Silicon Valley are really smart, and they're really successful because they can overcome any problem they face," says Bill Bishop, a digital-media entrepreneur with experience in both markets. "I don't think they've ever faced a problem like the Chinese Communist Party."

Matt Sheehan is a fellow at MacroPolo and worked with Kai-Fu Lee on his book AI Superpowers.

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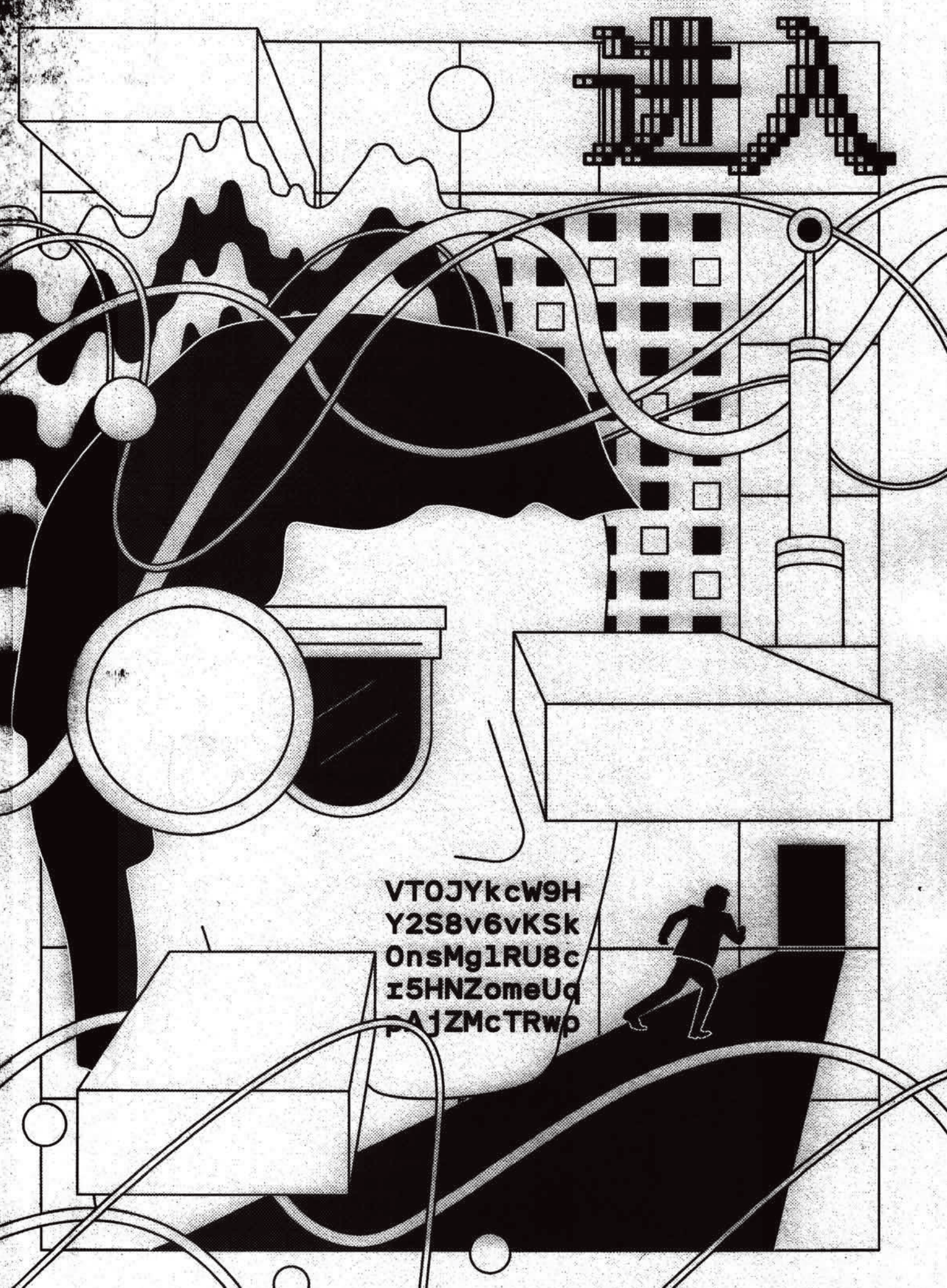
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By Chen Qiufan
translated by Emily Jin and Ken Liu

Illustrations by George Wylesol

The Reunion

Though only 23 minutes on the high-speed rail from Shenzhen North to West Kowloon, the journey from the mainland to Hong Kong seems to transport me back half a century. The concrete jungle of my childhood memories hasn't changed one bit. Time seems trapped in the amber of this city of seven million, while the Shenzhen Bay area that I departed has already arrived at the future ahead of schedule.

My classmate from a decade earlier, Dr. Ng Lok Tin of the Hong Kong University of Science and Technology, waits for me at the station exit. As though to highlight the discombobulation of modern China, he greets me in Cantonese though he's a native of Shanghai; I, Hong Kong born, on the other hand, speak to him in Modern Standard Mandarin.

"Leung Wah Kiu, what's this really about?" he asks me.

"A few days ago, two plainclothes officers approached me to ask if Professor Lau had been in touch and for the contact info of his relatives and friends in Hong Kong."

"I thought he had been placed in compulsory treatment some time ago?"

"Right, in a special care center in Shenzhen. But he broke out and escaped to Hong Kong, and they've lost his trail. We have to find him before the police do."

"Why?" Ng Lok Tin examines my face carefully, as if evaluating my sanity. Then realization dawns. "You don't believe he's gone mad at all, do you?"

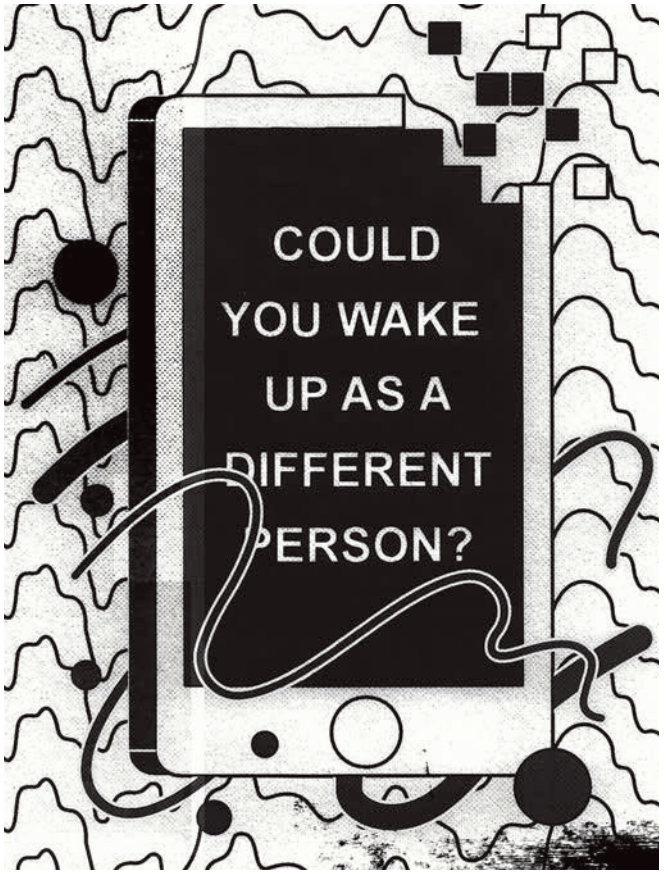
"I won't know until I see him in person." I can't keep the uncertainty out of my voice. "Help me, please."

Professor Lau Gim Wai, a leading expert in neurobehavioral imaging, had mentored us both in school. However, to me, he's much more than just a teacher.

More than a decade ago, when I was breaking under the stress of my PhD thesis and despondent from estrangement with my family, Professor Lau sent me e-mails daily, quoting lines from his favorite movies in his signature. Although he never said so explicitly, I knew that those lines—warm, encouraging, and uplifting—were meant for me.

I've never even seen some of those movies, but I remember every single quote he sent.

"If you wake up at a different time, in a different place, could



you wake up as a different person?" —*Fight Club* (1999)

When I became a different person on that rainy night, he was the one who saved me.

I must find out what has gone wrong with Professor Lau and his DISCO algorithm.

Lau developed DISCO ("distributed inter-subject correlation observer") on the basis of the inter-subject correlation (ISC) model from neurobehavioral imaging.

In traditional fMRI, the researcher must strictly limit the variables in order to study the correspondence between cognitive processes and brain regions. But results from such artificial lab settings are difficult to generalize to the complexities of real-life scenarios. Attending a concert, listening to a bedtime story, watching a movie … the brain is subjected to the influence of a host of uncontrolled factors such as the environment, mood fluctuations, and spontaneous social interactions.

The ISC method is based on the following conjecture: in the same natural setting, assuming everyone's brain has the same biological processes, identical encephalic regions should activate when different individuals encounter the same stimulus. For instance, if two people watching the same horror film together show similar heightened amygdala activity, then we may conclude that the amygdala is involved in the experience of fear. If the reactions of numerous individuals in the same natural setting are measured simultaneously and compared, one can safely ignore interference from most uncontrollable factors.

Lau's DISCO takes the ISC method to another level.

After the Spring City Railway Station attack more than a decade ago, similar random mass killing incidents proliferated, like a contagious disease with no apparent transmission route. Perfectly ordinary individuals, their lives unremarkable until that moment, would suddenly transform into vortices of violence, lashing into crowds with butcher knives, poisoned needles, even broken bottles, and deal as much damage as possible before the police could intervene.

As in the epidemic of suicides among migrant workers years earlier, there was at first no consensus about the underlying cause. Was it the pressure of technology-dominated, "ultra-unreal" life in modern China, where centuries of progress elsewhere had been compressed into a handful of decades? Was it the manifestation of a conflicted society that had lost its old, failed ideals with nothing new to take their place? Or was it something darker?

In the end, the authorities announced that the perpetrators in every single case were determined to have suffered from a form of mental illness unlike any other, leading to outbreaks of extreme violence. Though there was an official Latinate name for the diagnosis, most people called it "ATGism," for "against the grain." Pressure mounted among the public to preemptively confine individuals deemed to suffer from this condition.

However, traditional methods of psychiatric diagnosis left too much room for subjective interpretation, and the legal process for involuntary commitment was unwieldy and subject to abuse. The government became embroiled in controversy after controversy.

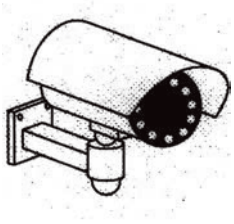
As the attacks continued, many began to question whether the government's involuntary commitment system was sufficient in preventing violence. At the same time, many patients who had been diagnosed using unreliable traditional methods—some of them showing no propensity to violence whatsoever—were deprived of personal liberty unjustly, resulting in much public anger. Yet the government couldn't simply abolish the old involuntary commitment system with nothing new to take its place, because many mental patients would be sent back to their families. Lingering prejudice against mental illnesses meant that many families, terrified, would cast these patients out into the streets, leading to even more social mayhem.

Just when the Ministry of Mental Health was at its wits' end, DISCO arrived on the scene like a deus ex machina.

Drawing on the enormous and comprehensive data bank of surveillance camera footage from mainland China and patient

data from Huilongguan Mental Hospital, the largest psychiatric institution in Asia, Lau was able to train and iterate the DISCO algorithm hundreds of billions of times. Unlike traditional neuroimaging methods like MRI, PET, and DTI, which depend on specialized hardware, DISCO can diagnose, surveil, and warn of imminent violent outbursts from ATGism solely though voiceprints, nonverbal expressions, and changes in behavioral patterns.

Lau only intended for DISCO to become a reliable tool for diagnosis, so that the ill could be helped and the well could live in security. But the government had bigger ideas in mind.



DISCO turned out to be easily adaptable for the T2000 Deep Gaze smart surveillance cameras, running as a distributed computing network. The algorithm was trained to recognize the new illness, but what other forms of deviance could catch its gaze?

I don't know whether the complexity of a human being can be reduced to a set of numbers, numbers that would then infallibly predict the propensity for violence. I do know that Professor Lau was identified by his own algorithm as a dangerous individual, and committed to compulsory treatment.

Do I think he's mad? I must find him first.

We begin with the most rudimentary form of investigation: talking to Professor Lau's family and friends one by one. As a fugitive, Professor Lau wouldn't dare expose his biometric data to the system, so there's no point in searching hotel guest lists.

We wander through public housing tenements as densely packed as ant nests; underground eateries redolent of mold; long, dark, twisting corridors. We are scrutinized by suspicious eyes peering from behind rusty gates. Economic decline and stagnation are even more visible than when I left, the consequence of Hong Kong's loss of status as a special tariff territory in the West during the trade wars.

We find nothing.

"What should we do now?" Ng Lok Tin asks as we sit down in Café de Coral.

"Let me think," I muse. "He took great risks to come to Hong Kong after escaping from the treatment center. Why? What's he hoping to accomplish here?"

He shrugs. Then his eyes brighten. "Oh, I invited him to come to our film festival a few months ago—I guess he must already have been committed by then—but all I got was an automated e-mail response."

"What film festival?"

"Didn't I tell you? I'm the neuroscience advisor for the Mind Wanderer Film Festival." Ng Lok Tin points out the window at an electronic billboard over the streets of East Tsim Sha Tsui, which is flashing through various film posters. "Tomorrow is our last day."

"Why would a film festival need a neuroscience advisor? I don't remember you being much of a film buff, either."

"Hey, that was years ago," he says sheepishly. "Anyway, now we use ISC technology in filmmaking too. I thought Professor Lau would enjoy seeing this alternate application of the technology."

"Is that why he came back?" I mutter to myself. "Films …"

As a young man, Professor Lau once dreamed of becoming a director, but his parents pressured him into medical school instead. Whenever he got a break in his busy schedule, he rushed to the cinema to catch a new showing. In our lab, he often conducted ISC studies using films as the stimuli. I suppose that was the best way he found of combining work and hobby.

"Do you really think Professor Lau escaped from the hospital and the police just to see movies in Hong Kong?" Ng Lok Tin's eyes widened with incredulity.

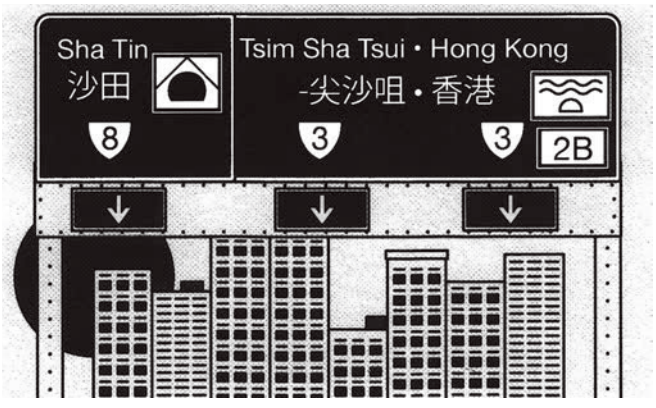
"Nothing so absurd." My mind churns, pondering this new angle. "But if you're telling me ISC is used in films, it's possible he wants to use his favorite research material to prove something. Like … his sanity. Do you still have that automated e-mail reply from him?"

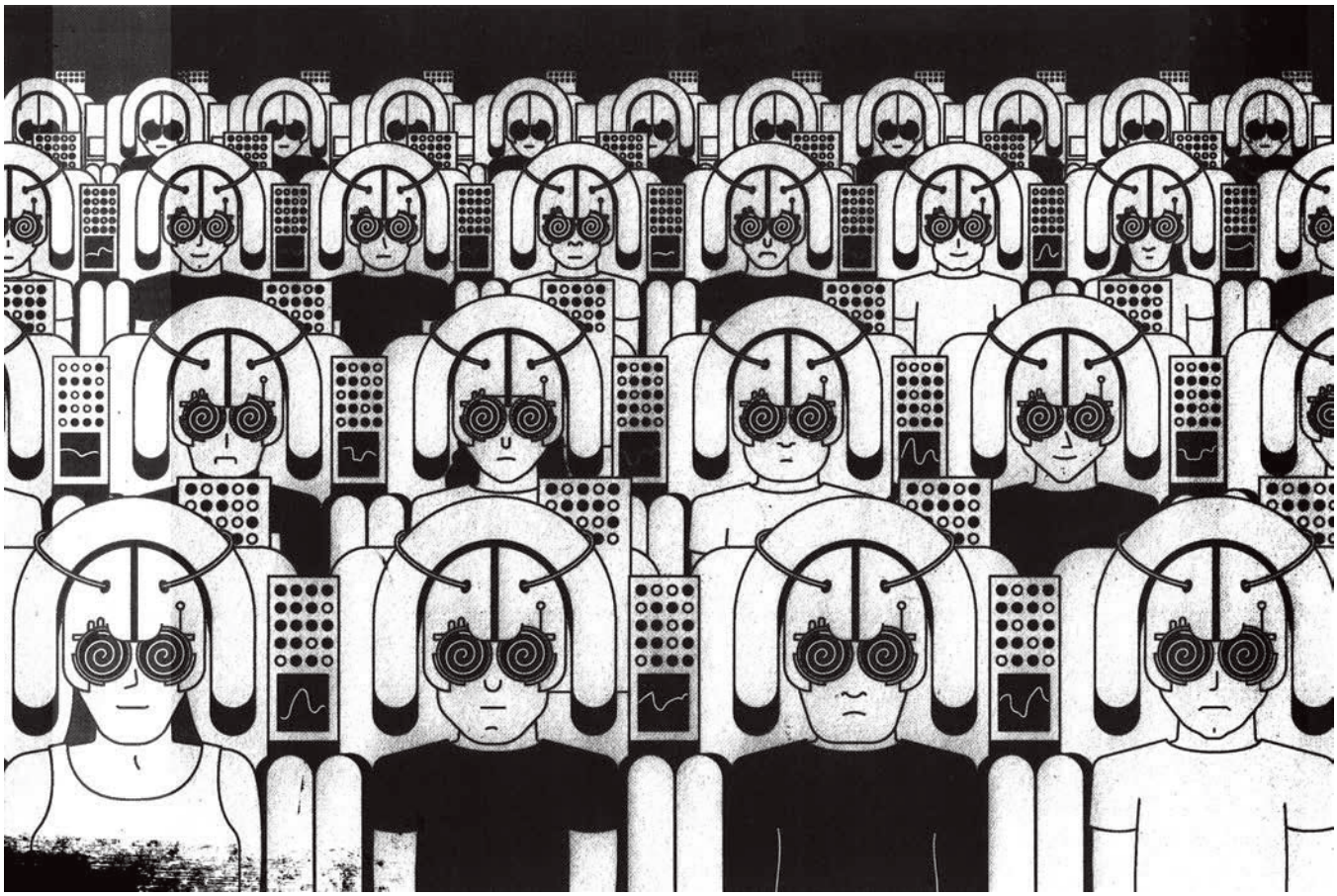
Ng Lok Tin pulls up Professor Lau's e-mail on his phone. My eyes are drawn to the quote in the signature:

"The mental defective league, in formation." —*One Flew Over the Cuckoo's Nest* (1975)

I focus on the date of the e-mail: the very day he was involuntarily committed.

As he realized that his algorithm had begun to turn on him, did Professor Lau try to send a message through his e-mail signature in the same way he once tried to comfort me?





We narrow the possibilities down to nine showings, the only ones using ISC projection. Six of them are scheduled between tonight and tomorrow morning, and the last three will take place simultaneously tomorrow afternoon.

From dusk to dawn—from Yuen Long in the northeast to Sai Kung in the far west—we rush to attend six ISC showings in six different theaters like a pair of fanatic cinephiles.

Along the way, Ng Lok Tin explains to me how the neuroimaging technique that led to DISCO found application in interactive entertainment.

In short, in ISC projection, miniaturized fMRI equipment is used to measure the neuroactivity of each audience member during key scenes. An ISC profile representative of the audience's overall neural response is then generated. But if any individual's measured response is two or more standard deviations from the average profile—essentially, if that person's neurological response to the key scene is sufficiently different from that of most people—the individual will be shown a specially designed hidden subplot. ISC-enhanced films have become very popular in Hong Kong because everyone wants to see if their brain is so unique, so above the vulgar crowd like an elegant crane towering above a flock of chickens, as to be given the prize of the special hidden subplot.

Maybe Professor Lau wants to use an ISC-enhanced film, powered by the same technology as the surveillance cameras, to prove that his neurological response does not deviate from the average profile.

"But how do you show a different plot to only some people in the same theater?" I ask, puzzled.

"You'll see for yourself soon." Ng Lok Tin grins mysteriously.

Ng Lok Tin's special advisor status gains us entry even after the start of a showing. As we tiptoe through each dark theater, we try to identify the man we seek among the hundreds of faces half hidden under helmets and eyepieces. We dare not bring up Lau's name, identity, or photograph to the staff or any audience member, lest we betray our intentions to special government agents after the same prey and perhaps lose our chance forever to find Professor Lau.

Everyone in the audience has their neck and shoulders secured

in place by rubber gear over the seat back in order to ensure clear neuroimaging scans. The silver helmets they all wear are attached to cables and processors behind the seats.

These helmets aren't for VR immersion; instead, the eyepieces are active shutter glasses synchronized with the projection screen's stroboflash, and the transmittance level of the liquid crystal lens can be altered many times per second. By carefully modulating the shuttering of eyepieces on two helmets, it's possible to show two viewers different frames from the same sequence. The refresh rate of the eyepieces must exceed 60Hz to prevent the brain from perceiving jitters. In order for the same screen to present two different dynamic pictures simultaneously during the ISC-enhanced segments—one for the main film, the other for the hidden subplot—the refresh rate of the screen must therefore exceed 120Hz.

A very clever design—it preserves the communal experience of watching a film in a theater while leaving room for the select few to experience hidden subplots.

Before key scenes, a green light flashes from the movie screen, indicating that the audience should hold still. When the light turns red, the scan begins, each lasting 6 to 15 seconds while the movie plays on. The real-time scanning data is transmitted to the processors behind the seats, corrected for linear drift and standardized. Then each person's scan result is uploaded to calculate the group correlation coefficient on the same time series. Finally, each individual's result is compared with other results to determine the version of the film that the person will see next.

As we canvass one theater after another, we experience the downfall of a newspaper tycoon, a beautiful dance in the rain, a monster hatching from its cocoon, a roaring tide of blood gushing from a gate. In the darkness, it's easy to tell which eyepieces are out of sync with the others through a phone camera app—like the different glows of sea glass and seashell in moonlight.

We never find Professor Lau in the audience.

We slump down onto the bench in front of the last theater at dawn. Even the golden sun can't cast away our clouds of frustration and weariness. The final three ISC showings are all in the afternoon, taking up the same time slot. Even if we split up and take one theater each, we'll miss the third showing, which means a one-third chance that we'll miss Professor Lau.

Besides, our whole plan is founded on the unproven assumption that the signature in that auto-reply was a meaningful hint, not our own wishful thinking.

"ISC projection is just a gimmick to get more people to come to the theaters, right?" I tilt my head toward Ng Lok Tin.

Instead of directly answering, he poses a question of his own. "Do you remember the argument we had right before graduation?"

"Sure. Professor Lau invited us both to join his development team. You not only declined the offer right away but were also, frankly, quite rude."

"I was too immature back then …" He bows his head, smiling awkwardly.

I remember how Ng Lok Tin contradicted Professor Lau. There could never be an objective, unchanging definition of mental illness, he said; the Diagnostic and Statistical Manual constantly evolved and was updated as science and ethics advanced. The use of neuroimaging technology in the diagnosis of mental illnesses had to be carefully considered. Society defined madness as the result of a combination of medicine and politics. Ultimately, a comprehensive and compassionate diagnosis required accounting for neuroimaging, behavioral data, social mores, and a multiplicity of other factors. To give undue weight to certain factors simply because they were easily measurable would lead to far greater problems.

Professor Lau looked exasperated, but instead of refuting Ng Lok Tin, he had coldly waved him away.

"Has your stance on this matter changed?" I ask.

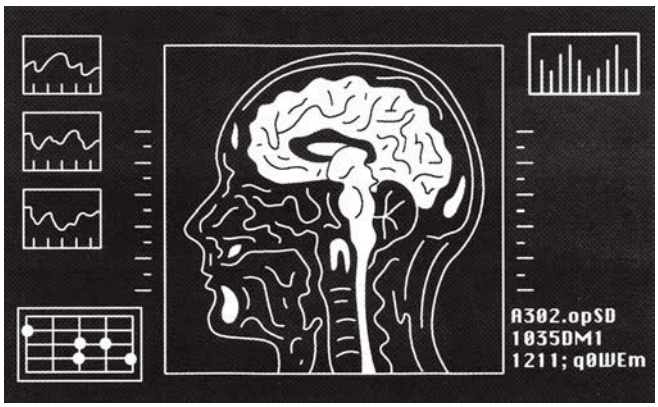
Ng Lok Tin seems to avoid my question. "Even though ISC films are now all the rage in Hong Kong, did you know that the technology was invented first in Dongguan, the Chinese city striving to be the world's entertainment technology leader? They beta-tested the technology in a few major theater chains, but the initial result was utter failure."

"What happened? Because of censorship?" In mainland China, cultural creativity is far less acceptable than technological creativity.

"Because no one ever saw the hidden subplots during the beta tests!" Ng Lok Tin bursts into laughter. "Don't you find that hilarious?"

I roll my eyes at this attempt at cynicism; he turns somber.

"You think letting a supposedly impartial algorithm define who's mad or deviant will help people live with more dignity



and security," Ng Lok Tin says. "But I believe the only thing the algorithm is good for is entertainment."

When Professor Lau invited his two favorite students to join his project, Ng Lok Tin and I made opposite choices. I followed my mentor up north to the mainland to develop his embryonic technology under government support. I saw no future for myself in Hong Kong, where nostalgia for a past that never was made people fearful of embracing the new. An algorithm that would pinpoint sources of violence couldn't be perfected without evolution in the real world, with real data, with real patients, with real consequences.

Ng Lok Tin, on the other hand, stayed behind in the ivory tower, intending to construct a delicate palace of theory woven from jargon and numbers and seek a perfect solution that would somehow account for all the factors.

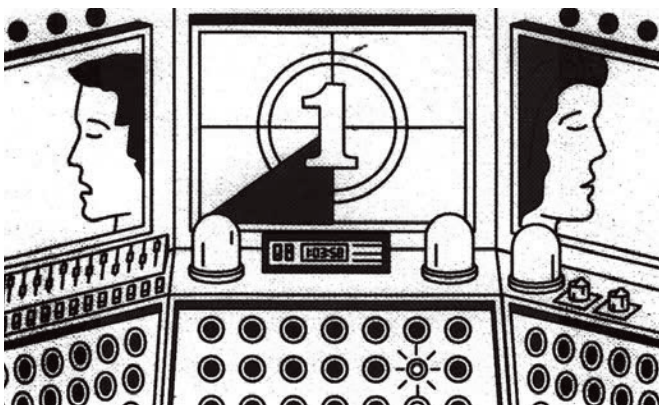
Now, a decade later, the plots of both our lives seem to have taken unexpected turns.

Two years ago, on the verge of mass deployment of DISCO surveillance, Professor Lau transferred me out of the core research group with the official excuse that I would be "appointed with other tasks." I was set up with a sinecure in a mental-health management agency in Shenzhen. Professor Lau never gave me a clear explanation of the abrupt change, but deep down, I knew that it was because of what happened that rainy night.

Had he already lost faith in his algorithm then? Did he send me away from the developing algorithm, hungry for all observation, to protect me? I'll never know unless I find him.

Meanwhile, back in Hong Kong, where residents took to the streets in protest and blocked the installation of DISCO-enhanced surveillance cameras, Ng Lok Tin ended up applying the same technique to peer into the deep recesses of every moviegoer's consciousness, manipulating them to indulge in the fantasy that they were somehow special enough to see a different story.

Time makes us all traitors to the ideals of our youth. Humans are simply too complicated to be reduced to computable paths.



"Were we wrong to assume that we knew Professor Lau well enough to predict what he would do?" I let out a frustrated sigh.

Ng Lok Tin tries to comfort me. "As long as he's not actually mad, he must still follow patterns of behavior that are reasonable."

"But even if we're right that he wants to come to the ISC showings, there's no way the two of us can be at three different theaters at the same time."

All three showings are of the same film: Wong Kar-Wai's *In the Mood for Love*. Preoccupied, Ng Lok Tin stares at the qipao-clad woman on the poster. Lights blink around the poster, like robotic stars.

He yelps and jumps to his feet.

"I'm going to take you where you can see three movie showings at once."

We arrive at the central control room at the Broadway Cinematheque in Yau Ma Tei. Here, we can see the real-time data from all three ISC showings visualized in arrays of lights. The other two showings are happening at the Grand Windsor Cinema at Causeway Bay and the Movie Town at Sha Tin New Town Plaza.

The staff checks and double-checks all the equipment. A countdown begins on the big command screen as though the place is about to launch a rocket instead of showing an old film about an extramarital affair. The director, known for his protectiveness, won't allow theaters to modify frames from the original film by adding flashing ISC signals for key scenes. Therefore, the theater has erected electronic call-boards next to the screen to remind the viewers when they should be prepared for scanning.

This gives us a chance.

I've never liked this movie, not because of the story itself, but because the artistic shots—streets full of buildings imitating a past that never existed, Tong Lau tenements, and drenching storms that one never learns to expect—call forth memories that pour down on me like heavy rain, until I feel I'm drowning.

Ng Lok Tin notices my discomfort. He wraps an arm around my shoulder and reassures me that we'll find Professor Lau no matter what.

He knows nothing of the tumult in my brain right now.

Finally, the movie arrives at that well-known scene in the Goldfinch Restaurant. The dim glow of the light, the green tablecloth, and the wallpaper enhance romantic tension. Maggie Cheung, in a qipao, stirs her coffee with a small spoon. Tony Leung, sitting across from her, frowns, a look of melancholy in his eyes. In the next scene, these neighbors will come to terms with the ugly truth: their spouses are having an affair with one another.

The ISC countdown begins, reminding the audience to sit still and prepare for scanning.

A line of text appears on the call-board.

Professor Lau, thank you for finding me. —Kiu

For most in the audience, this non sequitur, a little sappy, seems utterly incongruous with the tense, oppressive mood of the scene on the screen, a bit of random irrelevance to be ignored. It isn't meant for them.

But for Professor Lau, if he is among the audience, his brain should automatically seize upon the stimulus, trigger the retrieval of a certain long-ago memory from the hippocampus, and prompt the amygdala to produce an intense emotional response.

A rainy night 10 years ago.

I remember nothing of the beginning of the episode. After it was all over, my classmates informed me that after suffering a sudden breakdown, I had run out of my room and disappeared into the unexpected storm, through the faux-antique streets, past the buildings blurred by rain. My friends looked for me everywhere without success.

As I regained consciousness, I realized that I was standing outside the library's 24-hour study room with a jagged piece of broken glass in my hand. The students inside, their heads still buried in books, had no idea how close to death they had come. In fact, they were unaware of even my presence.

Professor Lau crouched before me, a wan smile on his face. Blood gushed from the deep wound in his palm, dribbled down his fingertips, pooled in a deep crimson patch at his feet.

"Everything is okay now, Ah-Kiu. I found you."

He and I are the only ones to know what happened that night.

I could have been committed. I could have lost everything. But he had found me and kept my secret. Why did he trust that there would be no further episodes from me? Why did he believe I had stepped back from the brink of madness?

There are no answers for some questions. Human beings are too complicated.

The arrays of glowing dots representing the ISC coefficients of the audiences at all three theaters light up simultaneously; like hundreds of twinkling blue stars, they brighten and dim in synchrony, as though breathing. Abruptly, one dot flashes orange instead of blue, but after a split second, it blends back into the anonymity of the arrays.

"Causeway Bay!" I dash for the door.

It only takes 13 minutes to get to Causeway Bay via the Cross Harbor Tunnel, as long as traffic doesn't get in the way, but the car ride feels like an eternity. On the way, Ng Lok Tin and I make plans for every contingency. But the hardest factor of all to control is how Professor Lau will react upon seeing us.

"See? It's impossible to predict individual behavior because even the smallest disturbance can lead to major deviations." I have no idea how Ng Lok Tin can still be in the mood for a lecture. "Yet when we change the scale and examine humanity as a collective, we can easily discern predictable patterns."

"I hope that Professor Lau and you can continue your debate from 10 years ago. You have new arguments, and no doubt he does too."

Ng Lok Tin shrugs, as if to say that he will most definitely win.

By the time we enter the theater, the credits are already rolling. Slowly, Ng Lok Tin and I search through the darkness, squinting at the faces in each row. All of them, half-hidden beneath helmets and bathed in a silver light, look the same to me. I move as slowly and softly as possible; I don't want to miss or startle the man.

Ng Lok Tin and I stop at the same row.

Professor Lau has already removed his helmet; the massive screen's silver glow glistens on his bare face. He gives me a look and points at the screen.

I turn. A quote from *Tête-Bêche*, the novel on which *In The Mood for Love* is based, floats on the screen. In French, tête-bêche refers to a pair of adjoining stamps printed upside-down relative to each other.

"He remembers those vanished years. As though looking through a dusty windowpane, the past is something he could see, but not touch. And everything he sees is blurred and indistinct. If he could break through that dusty windowpane, he would return to those vanished years."

My eyes dart back to the man, fearful that he'll disappear into the crowd at any moment.

Instead, he walks up to us. Ng Lok Tin staggers over to join our reunion.

"Professor Lau, we found you," I blurt out.

In the darkness, everyone is waiting for the end of the film.

Professor Lau Gim Wai smiles, as though to say, *It's not you who found me, but I who found you.*

Some things, like that orange glow deviating from a sea of blue, can be measured and ascertained. But what cannot be measured is the meaning behind that glow, the rainy night, the broken glass, the faith that madness and sanity, deviance and conformity, cannot be so easily pinned down.

"I need your help," he whispers. "DISCO is fatally flawed. Nuances of life neglected by the algorithm are critical in determining the fate of an individual—or rather, the fate of multitudes."

Smiling, Ng Lok Tin and I look at each other. This is not the ending, but the beginning of a new subplot.

Chen Qiufan (a.k.a. Stanley Chan) is a science fiction writer living in Beijing; his novel Waste Tide will be published in English by Tor Books in 2019. Emily Jin and Ken Liu have translated many works of Chinese science fiction, and Liu's own story "Byzantine Empathy" is in MIT Technology Review's latest Twelve Tomorrows anthology.

Cold comfort

By Graham Webster

Calling the US-China technological rivalry a cold war evokes an idea that is convenient and familiar, but wrong.

In recent months the New York Times has reported that "a cold war is being waged across the world's most advanced industries," that we are witnessing "the opening stages of a new economic Cold War," and that the rise of China fuels a generalized "new Cold War." A Wired headline last fall warned of "the AI cold war that threatens us all."

The comparison has dramatic appeal because it conjures two giants confronting each other over which will have the greater influence. The problem is that equating today's competition in tech with the Cold War ignores the reality of the US and China's interdependence and encourages policymakers' worst instincts.

So why do we keep hearing about it? Probably because the idea of a cold war is a convenient placeholder when it's so hard to describe what's actually happening: the unfolding of ideological and geopolitical tensions in a deeply connected and integrated technological environment.

Unlike the US and USSR, in which science and technology developed on largely independent tracks, the US and China are part of a globally intertwined ecosystem. As an example, ZTE, the Chinese maker of network equipment and smartphones, was nearly shut down last year by a US threat to cut it off from American semiconductors. Apple's devices, meanwhile, rely heavily on components and assembly in China, and the company makes one fifth of its revenue there. It would have huge problems if China were to cut it off from either its suppliers or its customers in retaliation for US tariffs.

Companies and innovators in both countries would suffer if international research, development, and manufacturing were to shut down. Meanwhile, even if the US and China cut off trade with each other, both countries would still have to worry about security risks from components, since risks along the supply chain exist everywhere.

In coming years both the US and China will face dilemmas about how to secure supply chains in an interconnected world. They'll both have privacy challenges. They'll both have to figure out how to regulate the proliferating uses of artificial intelligence. And along with every other country in the world, they'll have to deal with the risks of climate change.

But the cold war theme isn't just wrong; it's harmful. It assumes an existential struggle between competing blocs. It encourages political decision-makers to turn to bygone strategic concepts designed to fit the post–World War II era. It makes people on one side more hostile toward people on the other.

The analogy does at least provide an example of an outcome to avoid: a costly, destructive standoff between societies closed off from one another. There is real friction between the two countries, from different systems of government to military tensions over disputed territories to conflicts over intellectual property. We shouldn't stop being vigilant. But we can't stop being pragmatic, either.

NICO ORTEGA

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