Toro Hardy, Alfredo

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The technological contest between China and the United States

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The technological contest between China and the United States

Alfredo Toro Hardy PhD*

Abstract: China's proclaimed aim of becoming the world's leader in science, technology and innovation by the mid twenty first century has triggered an intense competition with the United States. The latter, feeling threatened in its supremacy in this field, has reacted forcefully. This GLO Discussion Paper examines the nature of this contest, the comparative technological standing of both countries, the pros and cons in this area derived from their respective development models and the plausible outcomes of this competition.

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Key words: Artificial Intelligence, China, Market economy, Research & Development, Science & Technology, State led model, Silicon Valley, United States.

*Retired Venezuelan career diplomat. Former Ambassador to the US, UK, Spain, Brazil, Ireland, Chile and Singapore. Author of 20 individual books, including his incoming *China versus the US: Who Will Prevail?*: https://worldscientific.com/worldscibooks/10.1142/11776.

I Introduction

Chairman Xi Jinping aims at China's "resurrection", which translates into converging strategies like the "China Dream of National Rejuvenation" or "Made in China 2025". The first pursues a powerful and prosperous China, the expansion of the country's geopolitical footprint, a focus on military power and military technology, and the change of China's strategic geography. [1] "Made in China 2025", on its part, aims at turning China into the world's leader in science, technology and innovation by the mid twenty first century. These objectives are perceived in the United States as a direct challenge to its supremacy. As a result, an intense competition between both countries has taken hold. Many speak of a new Cold War. Technology has become one of the main aspects of this confrontation.

Although China still keeps acquiring technology by "picking from the low-hanging trees", synonymous of easy access to foreign technology, it has become a powerful indigenous innovator. China and the U.S. are in direct competition in several key technological areas, with both parties enjoying of particular advantages within this process. Although China cannot aspire as yet to overcome the United States' technological superiority overall, the technologies in which they are competing have immense repercussion, as each of them has a multiplier effect over many other emerging technologies. This contest, though, is dependent on the efficiency of two very different technological development models: The State guided and funded one, and the market oriented one. Curiously enough, the Chinese have become the best pupils of America's innovation success story in the decades that followed WWII.

II Picking from the low-hanging trees

Indigenous innovation, that is productivity gains coming from its own R&D efforts, represent China's current technological stage. However, China's dynamic growth in this area was initially fueled by foreign technology. This represented the policy of technological progress by

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[1] Graham Allison*, Destined for War: Can America and China Escape Thucydides' Trap* [Kindle version] (Boston: Mariner Books, 2018), retrieved from Amazon.com, p. 109.

way of the so called “picking from the low-hanging trees”. This policy nurtured itself from many sources. Chiefly among them by buying technology, by financing the development of foreign technology, by forced technology transfer, and by stealing technology. Although at this point in time such easy source of technological acquisition has basically exhausted its growth possibilities, it coexists with the country’s potent indigenous innovation process. Hence, it has to be reviewed as part of China’s ongoing strategy.

Buying technology usually implies buying the Western companies that are producing it. This has gone from Volvo to MG, from IBM’s Personal Computers Division to Thompson, from Motorola Mobility to Cirrus Wind Energy, from General Electric Appliance Business to Ingram Micro, from the Chicago Stock Exchange to Pirelli. And the list goes on, including numerous medium size Silicon Valley companies.

A variation of buying the majority stockholding of foreign companies with desired technology, has been the acquisition of significant stakes in them. This has been the case, by instance, in relation to firms such as the German Lilium, the U.S.’ Xcerra or the U.K.’s Gilo Industries or Fine Organics. A study commissioned at the beginning of the last decade by the Asia Society in New York, forecasted that over the following years, China would invest as much as 2 trillion dollars to acquire overseas companies, plants or property.[2]

The closest thing to buying Western companies or parts thereof of its stockholding, is funding companies that are developing useful technologies. China has acted as a powerful source of venture capital both in the United States and Europe, aiming at technologies convergent with their own priorities. Silicon Valley has become one of its preferred destinations. A good example of such funding is illustrated by the case of Boston-Power.

This company started in 2005 to work on improving lithium-ion technology. Although successful in rising funds during the initial stages of its work, it fell outside the purview of American venture investment when it wanted to go into large-scale manufacturing. It was also unable to secure a US$100 million federal government grant for which it had applied. Fortunately for the company, China was willing to step in, providing a US$300 million low-interest loan

[2] David Barboza, “China’s Growing Overseas Portfolio, *International Herald Tribune*, 4 May, 2011.

through its venture firm GSR. Moreover, additional grants and subsidies followed. The Chinese government has been willing to invest, as this case shows, where private U.S. venture capital has not.[3]

It has been estimated that Chinese entities have poured about US$14 billion into U.S. startups since 2000, with 80 percent of the deals occurring since 2014. However, a new American law known as FIRRMA, expanded the powers of a previously obscure government agency called the Committee on Foreign Investments in the United States (CFIUS). Within its expanded authority, CFIUS will have to approve attempts by foreigners (meaning China), even to purchase minority stakes in U.S. startups. [4]

Next in line within the process of "picking from the low-hanging trees" is the forced technology transfer, as a precondition for doing business in China. This has been the case for countless foreign companies willing to access the gigantic Chinese market, which in 2018 exhibited a population of 1,393 billion people and a nominal GDP of US$14.2 trillion.[5] General Electric is a good example of such companies. In 2011, it handled over to China its most sophisticated aeronautical electronic technology, in order to benefit from this country's aeronautical market, which was expected to generate 400 billion dollars in sales during the next 20 years.[6]

According to the Peterson Institute for International Economics: "China has also adopted a set of policies deliberately designed to *force* foreign multinationals to transfer strategically

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[3] Jonathan Gruber and Simon Johnson, *Jump-Starting America: How Breakthrough Science Can Revive Economic Growth and the American Dream.* [Kindle version] (New York: PublicAffairs, 2019). Retrieved from Amazon.com., pp. 102, 103.

[4] Heather Somerville, "Chinese investments in U.S. startups peaks but 'tremendous uncertainty' ahead, Reuters, May 8, 2019, https://www.businessinsider.com/chinese-investment-in-us-startups-peaks-but-tremendous-uncertainty-ahead-2019-5. Accessed 8 October, 2019.

[5] The World Bank, Population, total, data worldbank.org, https://data.worldbank.org/indicator/SP.POP.TOTL. Accessed 8 October, 2019; International Monetary Fund, World Economic Outlook Database, April 2019, https://www.imf.org/external/pubs/ft/weo/2019/01/weodata/index.aspx. Accessed 8 October, 2019.

[6] Howard Schneider, "GE 'all in' on aviation deal with China, *The Washington Post*, August 22, 2011

sensitive technologies to indigenous Chinese firms. These policies are a key component of China's longstanding ambition to replace Western firms currently at the forefront of key technologies with Chinese national champions. In many cases, technology transfers are effectively required by China's foreign direct investment regime, which closes off important sectors of the economy to foreign firms unless they enter into joint ventures with Chinese entities they do not control. Examples of forced technology transfer abound in industries ranging from autos to information technology (IT)".[7] The Trump administration's trade confrontation is occurring on several fronts. The one against forced technological transfer is certainly the one that American companies are more likely to support.

The theft of Western technology is also in the list. Within a wider interpretation of this notion, forced transfer counts as technology stealing. In this case, of intellectual property rights. A more restricted interpretation of technology theft essentially would mean industrial espionage. American military and civilian technology has been stolen in grand scale by China's cyber espionage, with many of the U.S. targeted companies operating in sectors that Beijing considers important for their innovation purposes. The latter includes aerospace, semiconductors and information technology. An independent commission estimated that the annual loss to the American economy from the cyber-enabled theft of intellectual property, surpasses US$300 billion. Up to 80 percent of that theft may originate in China.[8]

According to Graham Allison: "'The amount of theft that's going on is simply staggering', FBI director James Comey said in 2014. 'There's only two types of big corporations in America.

[7] Lee G. Branstetter,"China's Forced Technology Transfer Problem and What to Do About It", Peterson Institute for International Economics, June 2018, https://www.piie.com/publications/policy-briefs/chinas-forced-technology-transfer-problem-and-what-do-about-it. Accessed 8 October, 2019.

[8] Lorand Laskai and Adam Segal, "A New Old Threat: Countering the Return of Chinese Industrial Cyber Espionage", Council on Foreign Relations, December 6, 2018, https://www.cfr.org/report/threat-chinese-espionage. Accessed 8 October, 2019.

Those who have been hacked by the Chinese, or those who don't yet know they've been hacked by the Chinese'". [9]

So politically sensitive is the subject that in 2015, President Barack Obama struck a deal that few thought possible. According to it, President Xi Jinping agreed to put an end to his nation's old practice of breaking into the computer systems of U.S. companies, military contractors and government agencies, to steal designs, technology and corporate secrets. Although for a while China's cyber espionage almost disappeared, it picked up again in 2018. Cybersecurity firms have reported a new hacking wave on U.S. companies. With the Trump administration restricting Chinese investments in high technology sectors, blocking Chinese telecommunication companies from doing business in the U.S., and imposing tariffs on Chinese imports, Beijing may have reached the conclusion that it had little to gain by continuing to honor the 2015 agreement.[10]

Direct espionage is another form of tech theft. In fact, spying for the State may have become a duty of Chinese citizens and corporations according China's 2017 National Intelligence Law. This demands that relevant Chinese organs, organizations and citizens provide necessary support, assistance and cooperation to the State in national intelligence efforts. The law says that the State will grant "commendations and rewards to individuals and organizations that make major contributions to national intelligence efforts".[11]

As a result, according to Shen Lu and Robert Delaney: "In the past year, Trump administration officials -including FBI director Christopher Wray, senior White House figures and even the president himself- have portrayed Chinese studying in the US as threats to national security (…) But as the Trump administration has taken on a more antagonistic approach to China, Chinese students and scientist have been accused of spying on the US for Beijing".[12]

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[9] : *Destined for War: Can America and China Escape the Thucydides' Trap.* [Kindle Version] (Boston: Mariner Books, 2018). Retrieved from Amazon.com, p. 17.

[10] David E. Sanger and Steven Lee Myers, "After Hiatus, China Accelerates Cyberspying Efforts to Obtain U.S. Technology", *The New York Times*, November 29, 2018.

[11] Yi-Zheng Lian, "Where Spying is the Law", *The New York Times*, March 13, 2019.

[12] "'I am not a spy': Chinese students in US become 'cannon fodder' of politics", Inkstone, May 24, 2019, https://www.inkstonenews.com/politics/visa-processes-are-tightening-chinese-students-us/article/3011678. Accessed 25 May, 2019.

Moreover, Mark Magnier reported how while Indian workers are well accepted in Silicon Valley, China's tech workforce is being seen with mistrust. As he explains: "While Indian tech workers have flourished in the US, their Chinese counterparts have struggled to gain the same acceptance (…) Students, professor and researchers of Chinese descent face growing suspicion as potential spies (…) There's also a growing perception that Chinese workers more often violate non-compete clauses and divert crucial technology to Chinese state-linked ventures…".[13]

Paranoia seems to have taken hold on the U.S. government and tech industries, affecting in the process not only the US$13 billion yearly contribution that Chinese students represent to the American economy (as reported by Shen Lu and Robert Delaney), but the much valued contribution of Chinese scientists to the American research and development (R&D) effort. However, China's 2017 National Intelligence Law generates the unavoidable presumption that every Chinese citizen or company might become a tool on behalf of Beijing's intelligence gathering.

III China as indigenous innovator

Notwithstanding the contribution that the policy "picking from the low-hanging trees" represented to China's technological advancement, at this point in time indigenous innovation firmly stands on its two feet. China is well on its way to becoming an innovation superpower. On the one hand, its industries are getting closer to the technological frontier in conventional areas such as high-speed railways, electronics, automobiles, and aviation. On the other hand, the country is driving technological innovations in emerging areas such as Artificial Intelligence (AI), big data, robotics, renewable energy, e-commerce, space technology or next generation communication technologies.

A 2014 article of *The Wall Street Journal*, citing technological executives from different parts of the world, already referred to the innovation process in China in the following terms: "China's technology sector is reaching a critical mass of expertise, talent and financial firepower

[13] "The India advantage: Why China's tech workforce can't gain traction in Silicon Valley", Inkstone, October 30, 2019, https://www.scmp.com/news/china/article/3035391/india-advantage-why-chinas-tech-workforce-cant-gain-traction-silicon. Accessed 30 October, 2019.

that could realign the power structure of the global technology industry in the years ahead".[14] Many facts can prove this.

China has already nine of the world's 20 biggest high tech companies: Alibaba (number 5 with a market capitalization of US$407 billion); Tencent (number 7 with US$389 billion); Ant Financial (number 8 with US$150 billion); Bytendance (number 14 with US$75 billion); Baidu (number 15 with US$64 billion); Didi Chuxing (number 16 with US$41 billion); Xiaomi (number 17 with US$56 billion); Meituan Dianping (number 18 with US$38 billion); and JD.com (number 19 with US$31 billion). The remaining 11 companies are American ones, with no other country listed. [15]

China is the second-largest spender on R&D after the United States, accounting for 21 percent of the world's total of nearly US$2 trillion in 2015. The country's spending on R&D grew by an average of 18 percent per year between 2010 and 2015, which is more than four times faster than U.S.' spending. Within the next five to 10 years, China's R&D spending is expected to surpass that of the United States. Venture capital investment in China, another fundamental piece to spur innovation, leapt from US$3 billion in 2013 to $US34 billion in 2016, rising China's global share of venture capital funds to 27 percent. Although the U.S. still retains the primacy in venture investment, China's share is rising several times faster: in 2018 it had outgrown more than 15 times its capacity in relation to 2013.[16]

Since 2013, the world's fastest supercomputer has been located not in Silicon Valley but in China. Indeed, in the ranking of the world's fastest supercomputers, a list from which China

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[14] Juro Osawa and Paul Mozur, "The Rise of China's Innovation Machine", *The Wall Street Journal*, January 6, 2014.
[15] Mara Hvistendahl, "Land of Giants", *MIT Technology Review*, The China issue: 120th Anniversary Issue, January/February 2019.
[16] Briony Harris, "China is an innovation superpower. This is why", World Economic Forum, 7 February, 2018, https://www.weforum.org/agenda/2018/02/these-charts-show-how-china-is-becoming-an-innovation-superpower/. Accessed 10 November, 2018; Phred Dvorak and Yasufumi Saito, "Silicon Valley Powered American Tech Dominance – Now It Has a Challenger", *The Wall Street Journal*, April 12, 2018.

was absent in 2001, it has now 167. That is, two more than the United States. Moreover, China's top supercomputer is five times faster than the closest American one.[17]

According to *Science & Technology*, a publication by the U.S. National Science Foundation and the National Science Board: "China has become -or is on the verge of becoming- a scientific and technical superpower" in terms of R&D spending, technical papers, and technical workforce. Measured by the number of scientific papers published in all journals indexed by the Science Citation Index (SCI), China ranked second in the world in 2016, representing around 20 percent of the world's total. China's State Intellectual Property Office (CIPO), reported that in 2017 the number of patent applications increased 14.2 percent in relation to 2016, registering 1.38 million, of which 420.000 patents were granted.[18]

China plays a leading role in space exploration, being the only country that has articulated a long-term vision of space settlement and utilization. A good example of its prowess in this area was the unmanned Chang'e-4 probe, which touched down on the Moon's unexplored South Pole in 2019. It has been the sole country with the demonstrated capability to get to the lunar far side.[19]

China is also a world leader in Artificial Intelligence, having filled 473 of the 608 AI patents lodged with the World Intellectual Property Organization (WIPO) in 2018. With 186 unicorn start-ups in 2018, China is home to a third of the world's unicorns. It is, as well, the world's leader in renewable energy, having built more solar and wind electricity generating capacity than any other nation. Three of the world's five largest floating solar plants are in China, while it accounts for more than half of global electric car sales. At the same time, China makes more than half of the world's electric vehicle batteries. This innovation prowess is clustered in a series of world class technological hubs, which combine manufacturing with intensive research by universities

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[17] Graham Allison, *Op. cit.,* p. 18.

[18] *Richard P. Appelbaum, Cong Cao,* Xuaeying Han, Rachel Parker and Denis Simon: *Innovation in China* (Cambridge: Polity Press, 2018)*,* p. 68.

[19] Namrata Goaswani, "China Had a Head Start in the New Space Race", The Diplomat, May 29, 2019, https://thediplomat.com/2019/05/china-has-a-head-start-in-the-new-space-race/. Accessed 3 June, 2019.

and corporate laboratories. Among them, Zhongguancun, Shenzhen, Hangzhou, Zhangjiang and Dalian.

Besides the unfair advantage obtained through the policy of "picking from the low-hanging trees", China's technological advancement has been mainly based on three other factors: The support given by the State to technological development, the sheer size of the country and the educational effort undertaken by the State. Later on we shall refer to the first of these factors. Let us begin by the last two.

Size matters, and China has as much of it as can be had. Size, indeed, is relevant on many accounts. First, given its status as the world's largest factory, the supply chains of numerous industries, which include thousands of component technology suppliers, are clustered in China. Hence, its R&D activities can be effective in identifying and creating new combinations that lead to incremental innovation. In other words, this allows for important improvements in the structure, design or method of existing technologies. Second, China's domestic market of close to 1.4 billion consumers with a GDP per capita of US$15,000 in Price Purchasing Parity, promises sufficient return to cover the cost of ambitious technological undertakings. These include the cumulative learning process to catch up with frontier foreign technologies, or pursuing the development of expensive technologies. Third, in the same manner in which companies from around the world are attracted by the Chinese market returns, so are scientist from everywhere. In addition to all the local talent that China can muster, the country has also become a magnet for the best available international talent in science and technology.

The educational effort undertaken by China in the field of science and technology has been enormous. This is linked, as well, to the size of the country, as the magnitude of its population facilitates the gathering of human resources. However, China's tradition of emphasizing education is crucially important. The results of the last PISA (Program for International Evaluation Student Assessment) test, made public in December 2019, placed China as number one worldwide. In the three tested categories -mathematics, science and reading- Chinese students obtained the first spot. The test which evaluates 15-years-old students from the 35 OECD member countries, has been expanded to include students from 79 countries.

Hence, China's students surpassed those of the most privileged economies, including those of small countries intensely focused on education such as Singapore and Finland. [20] Moreover, from 1990 to 2010, Chinese enrollment in higher education rose eightfold, and the number of university graduates passed from 300,000 to nearly three million per year. In 2017, eight million students graduated from Chinese universities.[21]

While the government spends 20 percent of its budget in education, Chinese households also invest heavily in it, reaching levels equivalent to 50 percent of the government's education budget. [22] This covers students studying overseas or remaining at home. In relation to the former, China is the world's number one country in the number of its youngsters pursuing studies abroad. In 2016, 544,500 Chinese students were studying outside the country. For example, in the U.S. alone, Chinese students accounted for 16 percent of all doctoral recipients in science and technology in the 2015-2016 academic year. This is concomitant to an increasing ratio of graduate students returning home. As for those remaining home, eight million of new university students graduated in 2017, as mentioned above. Of that amount, a large percentage are graduates in science and technology (S&T). Between 2000 and 2014, the annual number of graduates in S&T increased from 359,000 to 1.65 million. During the same period U.S.' graduates in S&T went from 483,000 to 742,000. [23]

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[20] Moriah Balingit and Andrew Van Dam, "U.S. students continue to lag behind peers in East Asia and Europe in reading, math and sciences, exams show", *The Washington Post*, December 3, 2019; Jenny Anderson and Amanda Shendruk, QUARTZ, December 3, 2019, https://qz.com/1759506/pisa-2018-results-the-best-and-the-worst-students-in-the-world/?utm_source=email&utm_medium=daily-brief. Accessed 4 December, 2019.

[21] Jonathan Gruber and Simon Johnson, "To Counter China, Out-Invent It: Trump's Trade Wars Ignores the Real Threat from Beijing", *Foreign Affairs*, September/October, 2019.

[22] Yanfei Li, "Understanding China's Technological Rise", *The Diplomat*, August 3, 2018, https://thediplomat.com/2018/08/understanding-chinas-technological-rise/. Accessed 20 September, 2019.

[23] Briony Harris, *op. cit.*; Yanfei Li, *op. cit.*, John Wong, "China's Economy 2018: Stabilizing Slowdown to Gear up for a New Model of Growth, *East Asian Policy*, East Asian Institute, National University of Singapore, Vol. 10, No 1, January/March 2018; Richard P. Appelbaum, Cong Cao, Xueying Han, Rachel Parker, Denis Simon, *op. cit.,* p. 23.

But there has been not only a quantity increase in educational outcomes, but also a qualitative one. This is particularly the case of its elite universities. Tsinghua University, China's MIT, awarded 1,385 S&T doctorates in 2017, compared with 645 conferred by MIT itself. Moreover, Tsinghua produced more of the top 1 percent most highly cited papers in mathematics and computing, and more of the 10 percent of most highly cited papers in science, technology and engineering (STEM), than any other university in the world. Although MIT still retains the number one spot in STEM papers, Tsinghua is on track to becoming number one in five years or less. Moreover, China's share of STEM papers cited in Scopus, the world's biggest catalogue of abstracts and citations, rose from 4 percent in 2000 to 19 percent in 2016, more than America's contributions.[24]

IV United States' standing

Where does the United States' stand in relation to China's impressive advances? The answer admits no doubts at this point in time: As number one. As the technological superpower whose commanding status China wants to reach and eventually surpass. Three elements could attest to the above: First, the number of Nobel prizes awarded to the United States; second, the commanding rank of its top universities; third, its clusters of innovation.

In relation to the first of those elements, the U.S. is the highest Nobel prize winning country, with a total of 375 winners as to May 2019. The majority of these prizes have been in physics and physiology or medicine, but there has also been a substantial number of laureates in chemistry and in economics. Literature and peace are also in the list, but the bulk of the winners came from the scientific community, which confirms the top quality of U.S.' researchers.[25]

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[24] *The Economist*, "Academic Research: Looking to beat the world", November 17th, 2018.
[25] World Population Review, "Nobel Prizes by Country 2019", http://worldpopulationreview.com/countries/nobel-prizes-by-country/. Accessed 15 October, 2019; Ashley Kirk, "Nobel Prize winners: Which country has the most Nobel laureates?", *The* Telegraph, 12 October, 2015, https://www.telegraph.co.uk/news/worldnews/northamerica/usa/11926364/Nobel-Prize-winners-Which-country-has-the-most-Nobel-laureates.html. Accessed 15 October, 2019.

Conversely, there have been just 3 citizens of the People's Republic of China who have become Nobel laureates. One for literature, one for peace and one for physiology or medicine. In other words, just one came from its R&D community: Tu Youyou, Nobel winner in Physiology and Medicine by her research in combating malaria. [26]

The high quality of American universities is concomitant to the strength of its R&D community, which again is closely linked to its Nobel laureates. According to the Times Higher Education, of the ten universities producing the largest number of Nobel Prize winners since 2000, nine are located in the United States.[27] As for the ranking of American universities, they tend to be at the top of the different classifiers.

According to QS World University Rankings 2019, of the top 20, 11 come from the United States, including the first four. Of those 20, only one Chinese university is listed: Tsinghua University in the 17th position. The Times Higher Education World University Rankings 2019, places 15 American universities within the first 20. None of them is from China. The CWUR World University Rankings 2018-2019, has 16 American universities in the top 20 and not one Chinese university. The U.S. News & World Report Best Global Universities 2019 Rankings, has also 16 U.S. universities within the first 20, without any reference to China within this group. Finally, the ARWU Academic Ranking of World Universities 2019, has 17 American universities within the first 20 pack. Again, none is Chinese. In other words, only the QS World University Ranking includes a Chinese university within its top 20 list.[28]

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[26] The Nobel Prize, "Tu Youyou: Nobel Prize in Physiology and Medicine in 2015", https://www.nobelprize.org/prizes/medicine/2015/tu/facts/. Accessed 15 October, 2019.

[27] Ellie Bothwell, "Top 10 universities for producing Nobel prizewinners 2017", The World University Rankings, October 13, 2017, https://www.timeshighereducation.com/news/top-10-universities-producing-nobel-prizewinners-2017. Accessed 15 October, 2019.

[28] https://www.topuniversities.com/university-rankings/world-university-rankings/2019. Accessed 15 October, 2019; https://www.timeshighereducation.com/world-university-rankings/2019/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats. Accessed 15 October, 2019; https://cwur.org/2018-19.php. Accessed 15 October, 2019. https://www.usnews.com/education/best-global-universities/rankings?int=a27a09. Accessed 15 October, 2019; http://www.shanghairanking.com/Academic-Ranking-of-World-Universities-2019-Press-Release.html. Accessed 15 October, 2019.

Finally, among the reasons that define the U.S. commanding status in the technological arena, we find its clusters of innovation. These gather R&D laboratories from both corporations and universities, plus startup capital funds. There would be no Silicon Valley without the R&D that takes place at Stanford University, nor the Boston-Cambridge technological miracle without MIT. Corporate laboratories, on their side, translate into commercially viable products and prototypes, the more theoretical technological inputs coming from university labs. Amidst this crisscrossing of talent, venture capital funds are ready to support startups representing fresh projects and new talent.

This clustering of innovation is highly concentrated along the Atlantic and the Pacific coasts. About a third of all R&D laboratories (1,035) are located in the Boston-New York-Washington, D.C. Corridor, while another quarter of them (645) are located in California. Patterns of concentrating clusters are notorious around Cambridge, Route 128, and major transportation hubs that reach down as far as Route 270 around Washington D.C. Alternatively, in California's Bay Area core clusters in Silicon Valley, stretching south from Stanford Research Park to San Jose reproduce this pattern of innovation. But also, further south in California, the San Diego-Carlsbad and the Los Angeles-Long-Beach-Anaheim clusters continue the same trend. But together with the above, there are scattered areas of innovation also present in Seattle, Detroit-Warren-Dearborn in Michigan, Durham-Chapel Hill, North Carolina or the Philadelphia-Camden-Wilmington in Pennsylvania, New Jersey, Delaware and Maryland, to mention but a few of the most representatives. [29]

The feedback and reinforcing dynamic which combine Nobel laureates, the world's leading universities and the main global hubs of innovation, have turned the United States into a technological juggernaut. However, the simple fact that China has been able to challenge the *status quo*, gives rise to a highly spirited situation. Today, the U.S. clearly leads, but one or two

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[29] Richard Florida, "Where to Find Unsung Engines of Innovation and Economic Growth", Citylab, August 8, 2017, https://www.citylab.com/life/2017/08/the-clustering-of-rd-labs/531159/. Accessed 15 October, 2019; Justin Song "Up and Coming Tech Hubs in the US: 2019 Report", ValuePenguin, October 2, 2019, https://www.valuepenguin.com/identifying-tech-hubs. Accessed 15 October, 2019.

decades ahead the technological correlation between both countries may very well change in fundamental ways. This situation is being acknowledged by the U.S. high-tech establishment.

V Technological correlation between both countries

An Independent American Task Force admitted the following: "China is investing significant resources in developing new technologies, and after 2030 it will likely be the world's largest spender on research and development…China is closing the technological gap with the United States, and though it may not match U.S. capabilities across the board, it will soon be one of the leading powers in technologies such as artificial intelligence (AI), robotics, energy storage, fifth-generation cellular networks (5G), quantum information systems, and possibly biotechnology". [30]

According to the *Science and Engineering Indicators 2018* of the U.S.' National Science Foundation, although the United States is the global leader in science and technology, its global share of those activities is declining as other nations, and very particularly China, continue to rise. In ScienceDaily words: "The National Science Board (NSB) is the governing body of the National Science Foundation (NSF) and publishes the congressionally mandated report on the state of the U.S. science and engineering (S&E) enterprise every two years. The 2018 reports show the U.S. invests the most in research and development (R&D), attracts the most venture capital, awards the most advanced degrees, provides the most business, financial and information services, and is the largest producer in high-technology manufacturing sectors (…) 'This year's report shows a trend that the U.S. still leads by many S&T measures, but that our lead is decreasing in certain areas that are important to our country', said Maria Zuber, NSB Chair and Vice President for Research at the Massachusetts Institute of Technology. 'That trend raises concerns about the impacts on our economy and workforce, and has implications for our national security'".[31] The

[30] James Manyika and William H. McRaven, Chairs and Adam Segal Project Director, "Innovation and National Security: Keeping our Edge", Independent Task Force Report No. 77, New York: Council on Foreign Relations, September, 2019.
[31] "Report shows United States leads in science and technology as China rapidly advances", January 24, 2018, https://www.sciencedaily.com/releases/2018/01/180124113951.htm. Accessed 13 October, 2019.

National Science Foundation’s *Science and Engineering Indicators 2018,* as reported by ScienceDaily, compares the U.S. and China standing in several areas:

a) While the U.S. leads the world in R&D expenditures at US$496 billion (26 percent of the global total), China is in second place with US$408 billion (21 percent). However, since 2000 China’s spending in R&D increased 18 percent annually, whereas the U.S.’ one grew by only 4 percent. Venture capital investment, which supports the commercialization of emerging technologies, totaled more than US$130 billion globally in 2016. While the U.S. was number one, attracting US$70 billion, slightly more than half of the global total, China was number two with US$34 billion, that is 27 percent of the total. However, venture capital in China rose from approximately US$3 billion in 2013 to US$34 billion in 2016, climbing from 5 percent to 27 percent of the total, the fastest increase of any economy.

b) Knowledge and technology intensive industries, in which science and technology are key inputs, are a major part of the global economy, comprising nearly one-third of the worlds GDP. These industries are divided in two main sectors: business, financial and information services; and high-technology manufacturing. U.S. leads in business, financial and information sectors, representing 31 percent of the global share, while China represents 21 percent (although China experiences a 19 percent annual growth, the fastest growing rate). As for high-technology manufacturing, U.S. is number one with 31 percent of the global share, while China is number two with 24 percent (however China has more than doubled its share over the last decade).

c) Higher education provides the advanced skills that are necessary in knowledge-intensive economies. In this area, the U.S. awarded 40,000 science and research (S&R) doctoral degrees, the world’s largest, followed by China with 34,000. At the S&R bachelor’s degree level, China led with 22 percent of the total versus 10 percent for the U.S. (since 2000, the number of S&R bachelor’s degrees awarded in China grew by 300 percent). It must be noted, however, that of the U.S.’ awarded degrees both at the doctoral and bachelor’s levels, a significant share corresponded to foreign students, with Chinese quite a relevant number of them.

Brookings defines the technological challenge represented by China in the following terms: “While competition between the United States and China is intensifying, these two powers are increasing their distance between themselves and every other country in the world in terms of economic size, pace of innovation, and overall national power. This separation of the United States and China from the rest of the pack is being fueled largely by both countries’ technology sectors”.

China and the U.S. are in direct competition in several key technological areas, with both parties enjoying of particular advantages within this process. Although China cannot aspire as yet to overcome the United States’ technological superiority overall, the technologies in which they are competing have immense repercussion, as each of them has a multiplier effect over many other technologies. Of those areas we could mention a few: Artificial intelligence, fifth-generation cellular networks, superconductors, quantum information systems, and space control.

VII Key technological areas of competition.

1.Artificial Intelligence

AI is an area where the U.S. currently leads, but where China aims to become the world leader in 2030. Artificial Intelligence could be defined as the ability of machines to use algorithms to learn from data, and use what has been learnt to make decisions like humans would. Differently from humans, however, AI-powered machines can work 24 hours a day, seven days a week, and analyze massive volumes of information at once. Its ratio of errors is also significantly lower than that of their human counterparts. For decades, the AI revolution seemed within reach, but failed to arrive. Thanks to the development, over the past few years, of deep learning (the process through which machines can learn by themselves), this revolution finally arrived.

As a consequence, AI is passing from the age of R&D into the age of implementation. It is the equivalent of Thomas Edison’s harnessing of electricity, a technological breakthrough that allowed revolutionizing dozens of different industries while lighting cities and homes. Once harnessed, AI can also be turned into real-world applications. Although the U.S. has a clear advantage in the area of R&D, being clearly ahead on core research and benefiting of a larger talent pool, China exhibits several comparative advantages in this new implementation phase. For a start, it has a larger market scale, which translates into increased business opportunities; it has a much larger population, which means a greater data base to feed the machine learning process; it offers more dynamic and innovative opportunities for machines to learn (as exemplified by China's supper-app WeChat, which takes care of most of its users' daily needs); and it has legions of cutthroat profit-hungry entrepreneurs, willing to exploit new practical applications.[32]

Both countries are thus being propelled forward in AI by unique attributes that no other country can replicate, and in the process keep distancing themselves from the rest. According to a widely cited study by PricewaterhouseCoopers, by 2030 the United States and China are set to capture 70 percent of the US$15.7 trillion windfall that AI is expected to generate.

The different nature of their political systems also plays in China's favor, as it allows it to move faster in this area. The Chinese government does not curtail the recollection of real data, being on the contrary a voracious consumer of it for political control purposes. This unparalleled amount of real-world data provides China with a major leg up in developing AI-driven services. As Yansheng Huang, a professor at MIT's Sloan School, explains: "In AI and big data, China is surging ahead, there's no doubt. These are areas compatible with the government's politics…You just plunge ahead without privacy complaints, without safeguards, regulatory constraints. In a very crude sense, you can develop science very fast without constraints". [33]

The U.S. political system, on the contrary, is becoming highly sensitive in this matter. This hangs as a Damocles sword over the head of America's AI entrepreneurs, who are affected on a double account. On the one hand, more data means faster machine learning process. This benefits their Chinese competitors, who can move without constrains. On the other hand, because any success that the U.S. companies may attain in obtaining data from their American

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[32] Kai-Fu Lee, *AI Superpowers: China, Silicon Valley and the New World Order* (New York: Houghton Mifflin Harcourt, 2018).

[33] "China vs. the US: Who wins and who loses", *MIT Technology Review*, The China issue: 120th Anniversary Issue, *op. cit.*, p. 46.

customers will be turned against them for invading their privacy. Hence, a greater success makes them more vulnerable vis-à-vis their own government.

According to Kai-Fu Lee, former president of Google China and successful venture capital entrepreneur: "I believe that China will soon match or overtake the United States in developing and deploying artificial intelligence. In my view, that lead in AI deployment will translate into productivity gains on a scale not seen since the Industrial Revolution. PricewaterhouseCoopers estimates AI deployment will add $15.7 trillion to global GDP by 2030. China is predicted to take home $7 trillion of that total, nearly double North America's $3.7 trillions in gains".[34]

2. 5G technology

The 5G technology represents once-in-a-decade upgrade to the wireless systems. It is the fifth generation of cellular networks. Currently, wireless phone calls are routed through cell towers. With 5G, the link will be nearly direct cellphone to cellphone. This will enhance connectivity in remote locations, while allowing to connect sensors and robots. At the same time, it will enable vehicles, traffic control and factories to become more autonomous. As a consequence, it will fuel smart cities and digital economies, becoming the next key driver of the Fourth Industrial Revolution. Military equipment embedded with 5G communication devices will also become more autonomous and efficient.

It hardly comes as a surprise, therefore, the intense U.S. - China competition in this area, which is currently centered around Huawei. This Chinese company is in a prime position to snatch the lion's share of the 5G market, as it is way ahead of its competitors in this technology. Indeed, in May 2019, U.S. intelligence officials acknowledged that Huawei would be likely to control as much as 60 percent of the global 5G market. [35] As a result, it has become the target of the U.S.' government repeated attacks. Presently, the United States finds itself without a telecoms hardware champion that can compete with Huawei. This relates to its 1996 deregulation of this sector and its lack of national mobile standards, which allowed American carriers to choose

[34] *Op. cit.*, p. 18.
[35] Daniel W. Drezner, "Economic Statecraft in the Age of Trump", *The Washington Quarterly,* Fall 2019, p. 13.

among whatever mobile standards they preferred. Multiple standards, however, implied that economies of scale where difficult to attain.

As explained by Bengt Nordstrom, CEO of the Swedish consultancy firm Northstream: "In many aspects, the era from early 1990s to mid-2000s was lost time for the U.S. mobile industry". The fact is that Cisco System remains as the only major American telecommunication firm. Its U.S.' competitors, Lucent and Motorola, have been taken out of the equation by foreign acquisition, either of its stock or of its wireless network infrastructure assets. As it happens, though, Cisco System's sales in 2018 were of US$49.3 billion versus Huawei's US$100 billion. This means that Cisco has a difficult task ahead, if it wants to become a true competitor to the Chinese firm.[36]

Stalling Huawei's expansion into Western markets would thus give its American and Western competitors time to catch up, and so good reasons for Washington to keep putting obstacles on its way. However, legitimate national security concerns are also in line, especially so in view of the Chinese National Intelligence Law of June 27, 2017. This would compel Huawei to provide to the Chinese government accessed foreign information. Consequently, U.S. efforts in curtailing Huawei advancement are fed both by its desire to contain China's predominance in this area, and by reasonable national security apprehensions.

So far, Washington has had only a partial success in stalling Huawei's international positioning. Not even some of America's closest allies, indeed, seem ready to shut the door on Huawei. This company represents the standard bearer of a groundbreaking technology to which few seem willing to renounce. In Daniel W. Drezner words: "…the Trump administration months-long campaign to convince allies to block Huawei from participating in construction of their 5G networks failed. Only Australia has followed America's lead in effectively banning Huawei. NATO allies refused to do so, forcing the Trump administration to back down on its threats".[37]

In any case, Washington seemed to have been ready to deny Huawei access to U.S. products and technologies which were necessary for its operation. These included not only chips

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[36] Zen Soo, "Why the US failed at 5G", Inkstone, April 3, 2019, https://www.inkstonenews.com/tech/why-has-us-failed-produce-5g-telecoms-leader-challenge-chinas-huawei/article/3004458. Accessed April 4, 2019.

[37] *Op. cit.,* p. 13.

designed in America, but also the Android mobile operating system. But so it seems that walked back from this decision after the Trump-Xi meeting at the 2019 G-20 summit, and after concluding that this would have only benefited America's European competitors. However, as we will see next in the case of the silicon chips, this highlights China's vulnerability in depending on foreign providers. Not surprisingly, Huawei announced that it would soon release its own mobile operating system to supplant America's Android.

3. The chip

Superconductors represent another area of intense competition. While China is at the forefront of electronic products, it has been unable to master the production of integrated circuit microchips, on which such products depend. The chip illustrates both the lingering limitation of China's capabilities and its vulnerability in relation to foreign producers of these silicon structures. In 2018 the U.S. government brought China's company ZTE to the brink of bankruptcy, as a result of an export ban of American microchips to that company.

Although Washington later backtracked from this decision, the episode reminded China of why it needed to overcome its dependence on foreign technology, and very particularly of American one. Moreover, this case was highly relevant because more than the simple fate of ZTE, China's brilliant future in areas such as 5G technology, autonomous vehicles or quantum technology, are closely linked to America's designed microchip. Consequently, China made of the indigenous production of microchips a priority.

Fortunately for China, new types of chips are being invented fully to exploit the advances in AI. Artificial intelligence may, indeed, change the nature of the chip, allowing China to benefit from its strength in AI to leapfrog and even excel in the chip industry. Reporting about one of these new inventions, Shelley Fan said: "This week, a team from Pennsylvania State University designed a 2D device that operates like neurons. Rather than processing yes or no, the 'Gaussian synapse' thrives on probabilities. Similar to the brain, the analogue chip is far more energy-efficient and produces less heat than current silicon chips, making it an ideal candidate for scaling up systems".[38]

Chinese companies are deeply involved in this process as well, as Will Knight explains: "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…The timing of 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".[39] In other words, China's advances in AI came handily when its government wanted to push forward in the development of chips. A fortuitous situation that could turn out to be a very fortunate one for China.

In addition to this process of indigenous innovation, China was able to exploit a loophole in the U.S. legal and regulatory control, to gain access to America's chip design technology. The recent acquisition by a Chinese firm of Advanced Micro Devices (AMD), a struggling company with unique chip design technology, now allows China to design and produce chips on its own, presenting an important challenge for American companies like Intel.[40]

4. Quantum technology

Quantum information systems represent another area of intense competition. This is closely related to the fact that they have applications in multiple areas, including the military. In 2016 China evidenced a breakthrough in encrypted satellite quantum communication. This technology offers a double potential for whoever controls it. On the one hand, it will lead to development of new forms of secure and unbreakable communications. On the other hand, it will make it easy to break the encryption used by others to protect financial data and military

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[38] "Moore's Law is Dying. This Brain-Inspired Analogue Chip Is a Glimpse of What's Next", SingularityHub, September 29, 2019, https://singularityhub.com/2019/09/29/moores-law-is-dying-this-brain-inspired-analogue-chip-is-a-glimpse-of-whats-next/. Accessed 1 October, 2019.
[39] "The chip leap forward", *MIT Technology Review*, The China issue: 120th Anniversary Issue, *op. cit.*, p. 32.
[40] Evan S. Medeiros, "The Changing Fundamentals of US-China Relations", *The Washington Quarterly*, Fall 2019, p. 101.

secrets. China, which is racing ahead in this field, has the ambitions to create a globe-spanning constellation of satellites, representing a super-secure quantum internet. [41]

Meanwhile, the United States is ahead in building powerful quantum computers. Quantum computers will be able process vast numbers of calculations simultaneously. Moreover, they would boost machine learning and solve special set of problems many magnitudes of order faster than traditional computers. Google, IBM and Intel have been investing considerable amounts into quantum computing for several years. In addition to that, venture capital funds have also been investing heavily in this area.

At the beginning of 2019, America's IBM Q unveiled System One, which opens the door to the first integrated universal quantum computing system. In October of the same year, Google announced that it had achieved quantum supremacy. The term refers to the point at which a quantum computer can perform calculations "beyond the most powerful classical computer imaginable". Google's contention, though, was not accepted by its domestic competitor IBM. While controversy emerged between the two big firms, Harvard University announced at the end of October, that its scientists had already attained quantum supremacy. [42]

While both countries wrestle for the control of quantum information systems, each still retain comparative advantages in specific sectors. China dominates secure quantum communications, while the United States prevails in quantum computing. However, both are trying hard to catch-up with each other and surpass the other's strengths where possible.

5. Space competition

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[41] Amit Natwala, "Why China's perfectly placed to be quantum computing's superpower", Wired, 14 November, 2018, https://www.wired.co.uk/article/quantum-computing-china-us. Accessed 5 April, 2019.

[42] Edd Gent, "Investment in Quantum Computing Is Booming – But Will a Quantun Winter Follow?", SingularityHub, October 14, 2019, https://singularityhub.com/2019/10/14/investment-in-quantum-computing-is-booming-but-will-a-quantum-winter-follow/. Accessed 17 October, 2019; Tom Simonite, "IBM says Google's Quantum Leap Was Quantum Flop", Wired, 21 October, 2019, https://www.wired.com/story/ibm-googles-quantum-leap-quantum-flop/. Accessed 22 October, 2019; Alvin Powell, "Riding the quantum computing 'wave'", The Harvard Gazette, October 29, 2019, https://news.harvard.edu/gazette/story/2019/10/harvard-weighs-in-on-googles-quantum-supremacy/. Accessed 30 October, 2019.

A space control competition is also in motion between the two countries. The U.S. has spent considerable time trying to hinder the progress of Chinese space plans. In 2011 a U.S. law prohibited bilateral contacts between NASA and Chinese scientists, while Washington foreclosed China's participation in the U.S.-Russia International Space Station (ISS). However, this has not stopped China. While ISS future is in doubt and will most probably not survive beyond 2024 according to experts, China steadily advances towards the completion of its own space station in 2022.

At the same time, China is developing a space telescope that will have the same resolution than America's potent Hubble, while China's Long March 9 rocket scheduled for 2028 compares to America's Saturn V, still the most powerful rocket ever built. Moreover, Long March 9 will far exceed NASA's Space Launch System, also scheduled for 2028. The Long March 9 would be capable of landing a man on the moon and launching a Mars sample-return mission. Meanwhile, last December, China landed a robotic rover on the far side of the moon, being the first spacecraft to do so. It is important, nonetheless, to point out a difference between both country's peaceful space programs. While NASA's plans have shifted with each new administration and struggled to find support in Congress, the China Academy of Launch Vehicle Technology, CALT (NASA's Chinese counterpart), has had steady mandate and funding from the Chinese government." [43]

However, together with space's technology for peaceful purposes, there is a military side to it as well. Herewith the dual civilian-military nature of this technology, which is what makes this competition particularly sensible. China's advances in the military aspects of it have been very relevant, as briefly explained when referring to its asymmetric weapons in chapter seven. To respond to China's advances in this area, President Trump issued, at the beginning of 2019, Space Policy Directive-4, which formally established the United States Space Force as a new branch of the U.S. military. In other words, together with the Army, the Navy and the Air Force,

[43] Joan Jonhson-Freese, "The rockets' red glare", *MIT Technology Review*, The China issue: 120th Anniversary Issue, *op. cit.*, pp. 52-55.

there is now this new branch. This implies that its budgetary needs will be cover by the National Defense Budget.[44]

Another aspect of the U.S.-China space competition is provided by the private companies of both countries involved in this area. In 2014, the Chinese government allowed private investment in space-related industries. Amidst Chinese private startups we find Landscape, LinkSpace, iSapace or OneSpace. LinkSpace is planning to launch a vertical takeoff, vertical landing rocket in 2020. These "launch rocket" companies are operating hand in hand with a group of privately funded companies that are focused on performing specific tasks "in" space, rather than getting there. The U.S. on its side, has had private investment in the space sector for a long time. However, Elon Musk's SpaceX has changed the face of the American aerospace industry. After decades of domination of this sector by old-line companies, SpaceX has become most significant member of a new generation of companies that are dramatically lowering launch costs, while seeking to revolutionize both human space travel and satellite launching. In 2015, SpaceX's Falcon 9, made the first ever vertical landing of a rocket, a technology in which China's LinkSpace is also competing.[45]

VIII Competing development models

At the end of the day, this struggle for technological supremacy in certain key areas, and in general terms, is dependent on the efficiency of two very different technological development models: The State guided and funded one, and the market oriented one. While China follows the first, the U.S. follows the second.

China has focused state-led efforts on ensuring that science, technology and innovation propel the country as a fundamental growth engine. China's R&D as a percentage of GDP went from 0.9 percent in 2000 to 2.1 in 2016. At the same time, the country has set ambitious targets in technological capacity building in a range of specific sectors. Just between 2001 and 2011, the overall growth rate of its R&D surpassed the 20 percent mark annually. However, China has

[44] Peter Juul, Trump's Space Force Gets the Final Frontier All Wrong", *Foreign Policy*, March 20, 2019, https://foreignpolicy.com/2019/03/20/trumps-space-force-gets-the-final-frontier-all-wrong/. Accessed 30 October, 2019.

[45] Joan Jonhson-Freese, *op. cit.*, pp. 52-55.

continued to increase its R&D spending with the aim of overtaking both the European Union and the United States and becoming the world's top R&D spender in 2019. [46]

At the same time, it has stimulated private sector and venture capital efforts in this area, guiding them toward a set of strategic goals. As a result, China has not only some of the world's largest private high tech companies but has also become the second largest world market for venture capital investment. More than that, targeted technological priorities are getting directly both the energy and the funding: from public to private, from the national level to the state and municipal ones. In other words, a multiplier effect concentrated in key areas. Meanwhile, the State directs a large percentage of its annual budgets towards education, with science and technology as it main priority.

The combination of the State financial support for R&D, its sustained attention to science policy (including continued reform efforts), its support and guidance of the private sector's efforts towards strategic targets, and the sheer size of the science and technology talent pool resulting from the official efforts in education, have led to an explosive growth in scientific output.

The United States, as yet the leading technological superpower, has a market-oriented approach to technology. The private sector, on whose hands technology generation relies, focuses solely on assessing if the returns of any investment are high enough to justify the risks. This is the case of both high-tech companies when assessing new development projects, and of venture capitalists when judging about the merits of investing in a startup. Moreover, private R&D has increasingly turned away from basic scientific research and focused on applied one. This means emphasizing commercially oriented product developments at the expense of capital-intensive long-run research projects. As Victor Bulmer-Thomas refers: "There is nothing wrong with applied research, but it is unlikely to have the same transformative effects on the whole economy as basic research".[47] Until 1987 one-third of private R&D was still directed to basic

[46] Richard P. Appelbaum, Cong Cao, Xueying Han, Rachel Parker and Denis Simon*, op. cit.*, pp. 13, 14.
[47] *Empire in Retreat: The Past, Present, and Future of the United States* [Kindle version] (New Haven: Yale University Press, 2018), retrieved from Amazon.com, pp. 295, 296.

research, an amount which has fallen today to one-fifth. Innovation, as a consequence, is becoming more incremental and less able to produce technological breakthroughs. [48]

Both the Chinese State-led model and the American market oriented one, have shown cons and pros. China has evidenced an important misallocation of resources: "The central government still controls a significant share of the R&D funding, which is often distributed without necessary regard to merit or transparency; and its use has all too often been ineffective, wasted and abused". [49] In addition to that, State interference and the Chinese National Intelligence Law of June 27, 2017, which forces Chinese companies to become informants of the State, depict a serious flaw in the model. The latter generates a high and well-deserved degree of mistrusts against Chinese high-tech companies and scientists all around the world. This can hardly work to their advantage, imposing upon them a huge burden. Having said that, however, it is obvious that China would not have achieved its current global status in science, technology and innovation, had it not been for the State led model. The synergy resulting from the combined effort of all the forces of the nation in pursuit of common goals, has been simply overwhelming.

Clearly, within the U.S.' market oriented model, the kind of misallocation of resources seen in China are out of the picture. However, as the Edward Snowden revelations showed, electronic communications passing through the U.S. by way of Microsoft, Google and the like, had to be turned over to the United States National Security Agency (NSA), when they matched court approved search terms. Although not as intrusive as the 2017 Chinese National Intelligence Law, these revelations showed that the U.S. government's prying on information obtained by private companies was not out of the picture. The American model, though, has other serious flaws directly related to their market oriented nature.

As mentioned above, private companies are unwilling to invest if they do not foresee clear and full return from their investments. Hence, their scope is limited and mainly centered on product development. Meanwhile, financiers who support start-ups much prefer those that yield fast results (five years at the most) than those with potentially distant payoffs. That is, projects where the commercial viability is established quickly and where returns can be obtained equally

[48] Jonathan Gruber and Simon Johnson, *Jump-Starting America*, op. cit., p.107.
[49] Richard P. Appelbaum, Cong Cao, Xueying Han, Rachel Parker and Denis Simon*, op cit.*, p. 49.

quickly. As a consequence, capital-intensive long-run research projects, where major technological breakthroughs usually take place, are not the aim of either of them.

Alzheimer disease research is a good example of the former. According to James Hendrix, director of global sciences initiatives at the Alzheimer's Association: "The way our patent laws are set up doesn't work for the protracted studies into Alzheimer's treatment. Trials often take between five and ten years, sometimes more, before it can be determined if a drug or intervention is working. Patent protection and market exclusivity will likely be expired or nearly expired by that time. The loss of exclusivity makes it difficult for drug companies to justify the cost of the study".[50] Not surprisingly, little has been attained in this area, which represents a major global health problem.

As synthetized by Jonathan Gruber and Simon Johnson: "Private companies do not have an incentive to do the path-breaking research that moves the frontier forward for others. Private financiers are not structured to provide the large financial commitments to innovate in rapid-intensive areas".[51]

IX The State as catalyst for development

Curiously enough, the U.S. technological system would not be what it is today, had the Federal government not acted as a catalyst for development. This was the model that prevailed until a few decades ago, a period when breakthrough inventions paved the ground for what Silicon Valley and its other high-tech American counterparts are today. From the development of integrated circuits and the associated miniaturization of computer hardware to the Internet; from the GPS to magnetic core memory (a major breakthrough in terms of how to store and access data); from semiconductors to the satellite industry; the examples are countless. All of these inventions, the gigantic shoulders on which America's high tech stands today, would have not been possible without capital-intensive basic research and long-run projects. And this could not have been attained without a State guided and funded model.

The innovation that led to the U.S.' rapid growth after World War II was the direct result of a fruitful partnership between the private sector, universities and the federal government,

[50] Jonathan Gruber and Simon Johnson, *Jump-Starting America*, op. cit., pp. 97, 98.
[51] *Jump-Starting America*, *Ibidem*, p. 114.

where the last played the leading role. An essential part of this process was the meteoric transformation of higher education in America, including a great expansion in the number of university-formed engineers and scientists. Another essential part was the massive funding provided by the federal government to R&D: From 1940 to 1964, such funding increased twentyfold. At its peak in the mid-1960's, this spending represented around 2 percent of the annual gross domestic product. [52]

This process was the natural continuation to the State led effort to win WWII, with the invaluable support of the private sector and the scientific establishment. However, after the so-called Sputnik moment (the American shock resulting from the Soviet's launching of the first ever satellite to orbit Earth), such process received a new boost. In the decade that followed Sputnik, federal funding for research at universities increased by more than four times in inflation-adjusted terms. Funding for science education, including classrooms and laboratories, also increased dramatically. The most significant post-Sputnik development, though, was the Apollo program, which at its peak comprised 2.2 percent of all federal spending. According to NASA's count, at least two thousand products or services were helped into development and commercialization as a result of the scientific research that took place during those years. [53]

From mid-1960s onwards, a divergence of positions between the federal government and the scientific community began to take shape. Vietnam, no doubt, had much to do with it. Moreover, the budgetary pressures arising from the Vietnam War and the Great Society program, set new priorities. The election of Ronald Reagan in 1980, who had run on a powerful anti-tax platform, put in motion a retreat from federally funded activities. The combination of these different elements translated into a progressive but drastic withdrawal of the federal government not only from R&D funding but also as a driving force in scientific and technological innovation. Federal spending on research and development fell from 2 percent of economic output in 1964, to around 0.7 percent today. In Jonathan Gruber and Simon Johnson words:

[52] Jonathan Gruber and Simon Johnson, *Jump-Starting America.*, Ibidem, p. 6.
[53] Jonathan Gruber and Simon Johnson, *Jump-Starting America*, Ibidem, pp. 45, 46

"Converted to the same fraction of GDP today, that decline represents roughly $240 billion per year".[54]

Even so, this dramatically reduced funding percentage can still be sufficient to fulfill path-breaking research, when federal leadership is available. That was the case of the Human Genome Program. After the scientific community convinced the U.S. federal government to make of this a priority, Congress agreed to fund the National Institutes of Health (NIH) for research on the human genome. At the beginning 1988 this undertaking took off, and the National Center for Human Research (NCHGR) was created to coordinate the collective efforts of NIH, the Department of Energy, public research institutes, and private companies. Economic activity associated with human genome sequencing between 1988 and 2012 amounted, directly or indirectly, to US$965 billion. However, the NIH estimates that the Human Genome Program results have produced so far nearly US$1 trillion in economic growth. In addition to the medical sector, this has benefited pharmaceuticals, agriculture, biotechnology, biofuels, food processing, among many other industries. The breakthrough represented by the human genome decoding might have never been attained without the federal government leading the way.

Unfortunately, the above example represents the exception, not the rule. The withdrawal of the federal government has had catastrophic results in education, an area which it had championed in the past. In just one generation, the United States fell from the number one position to number 12, in the world's proportion of its young people with graduate degrees. In Arianna Huffington words: "Our high schools have become dropout factories. We have one of the lowest graduation rates in the industrialized world: Over 30 percent of American high school students fail to leave with a diploma. And even those who graduate are often unprepared for College. The American testing Program, which develops the ACT college admission test, say that fewer than one in our of those taking the test met its college readiness benchmark: English, reading, math and science (…) Even the top 10 percent of American students, our best and brightest, ranked only twenty-four in the world in math-literacy".[55]

[54] *Jump-Starting America*, Ibidem, p. 8.
[55] *Third World America* (New York: Crown Publishers, 2010), pp. 114, 115.

In the 2015 Program for International Evaluation Student Assessment (PISA), the U.S. score was significantly below the OECD average, while in the 2017 survey of thirty-five OECD countries the U.S. attained the thirty-first position in mathematics, the nineteenth in science, and the twentieth in reading. Not surprisingly, the most recent Stanford University comparison of students entering college in the fields of engineering and computer sciences, found that Chinese students arrive with a three-year advance over their American counterparts. [56]

Moreover, while the GI Bill unleashed the force of university education in the U.S., by providing tuition and financial support to WWII veterans wanting to go to college, 44 million of Americans currently hold around US$1.5 trillion in student debt. [57] Nearly three-quarters of a million veterans followed scientific education as a result of the GI bill, which democratized college studies in America.[58] Nowadays, by contrast, high costs have become an important deterrent to university education in the United States.

President Obama was able to capture the seriousness of the situation. In its 2011 Discourse of the Union, he made reference to the need for a new Sputnik moment. Moreover, during his period in office he also presented two insightful initiatives: Its "Winning the Future" agenda and its "Race to the Top" educational program. None of it, though, did translate into concrete results. The truth may be that a Sputnik type reaction to the current challenges, is no longer attainable.

The conditions have substantially changed since President Eisenhower, later followed by President Kennedy, assumed the challenge of not falling behind the Soviets in the space conquest. They were, indeed, able to count on the extraordinary capacity to build domestic political consensus that characterized their time. Building consensus around big national

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[56] Graham Allison, *op. cit.*, p. 16; Victor Bulmer-Thomas, *op. cit.*, p. 294., "U.S. students continue to lag behind peers in East Asia and Europe in reading, math and sciences, exams show", *The Washington Post*, December 3, 2019.

[57] Abigail Hess, "Here's how much the average student loan borrower owes when they graduate", CNBC, February 15, 2018, https://www.cnbc.com/2018/02/15/heres-how-much-the-average-student-loan-borrower-owes-when-they-graduate.html. Accessed 23 November, 2019.

[58] Jonathan Gruber and Simon Johnson, *Jump-Starting America*, ibidem, p. 36

objectives is something that has become unattainable nowadays, amidst an utterly and bitterly polarized Congress and society. Moreover, with a public debt that is now of more than US$22 trillion, massive federal expending of the kind undertaken by China is not politically feasible in the United States.

The private sector has virtually become the sole force in guarding the U.S.' high tech fortress, against China's formidable challenge. However, it is very much on its own within an inquisitive and regulatory ambience. While the threat of dismemberment hangs in the air for the most successful of them, the government has been inauspicious in helping them access the foreign talent that they lack at home. Who knows if a Werner von Braun, the German scientist who headed the American Space project, would have been allowed to work in the United States nowadays, due to H1B visa restrictions. According to New York's former mayor Michael Bloomberg, co-founder of "Partnership for a New American Economy", even though immigrants play a relevant role in three out of four patents at America's top universities, foreign born innovators face today "daunting or insurmountable immigration hurdles that force them to leave and bring their talents elsewhere.[59]

As things stand, it seems clear that the Chinese have become the best pupils in following the textbook of America's innovation success story in the decades that followed WWII. This includes a fruitful partnership between the private sector, academia and the State, where the latter plays the leading role, as well as the active promotion of university-formed engineers and scientists. Moreover, China follows the kind of capital-intensive basic research and long-run projects that once where the backbone of America's S&T development. China's route map in science, technology and innovation looks, indeed, much more coherent and holistic than the one been followed in the United States. In Graham Allison words: "Each of these achievements demonstrates China's ability to undertake costly, long-term, path breaking projects and see them through successful completion – a capability that has atrophied in the US".[60] If that is the case,

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[59] Andrew Martin, "Immigrants are crucial to innovation, study says", *The New York Times*, 25 June, 2012.

[60] *Op. cit.*, p. 18.

China might be able to attain its objective of becoming the world's leader in science, technology and innovation by the mid twenty first century.

X Conclusion

Independently of the advantages obtained through its policy of "picking from the low-hanging trees", China has become an extremely efficient indigenous innovator. China and the U.S. are in direct competition in several key technological areas. Chiefly among these are the following: Artificial intelligence, fifth-generation cellular networks, superconductors, quantum information systems, and space control. Each party enjoys of particular advantages within this contest.

Even if China is still not prepared to displace the U.S.' technological superiority overall, the technologies in which they are forcefully competing have immense repercussion. This, basically because of their multiplier effect over many other emerging technologies. This confrontation, however, is contingent on the efficiency of two very different technological development models: The State guided and funded one, and the market oriented one. Curiously enough, the Chinese have become the best pupils in following the textbook of America's innovation success story in the decades that followed WWII.

The Chinese route map in science, technology and innovation, looks much more coherent and holistic than the one been followed in the United States. Although the U.S. still commands the technological heights, trends seem to be pointing toward China's forceful emergence in a group of fundamental technologies. Moreover, should China be able to replicate America's post WWII technological success story, it might indeed materialize its aim of becoming the world's leader in science, technology and innovation by the mid twenty first century.

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